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Introduction

In the third lab, we designed a wide-band amplifier with a desired kind of feedback achieving low output impedance and flat gain. The following specifications were given in the manual. The designed circuit is as in Figure 1.

Specifications:

Source impedance: 500Ω

Load impedance: 47Ω

Mid band voltage Gain: 20 dB±0.5dB

Bandwidth (−3dB): at least 2KHz to 2MHz (by CNTL-Click in AC analysis)

Supply voltage: 12V (single supply)

Maximum current consumption: 70mA from the supply voltage

Undistorted peak-to-peak output voltage: $2V_{pp}$ at 200KHz.

Distortion at the output: Harmonics less than −30dBc at 200KHz $2V_{pp}$ output voltage (the difference between the fundamental and the highest harmonic in FFT window)

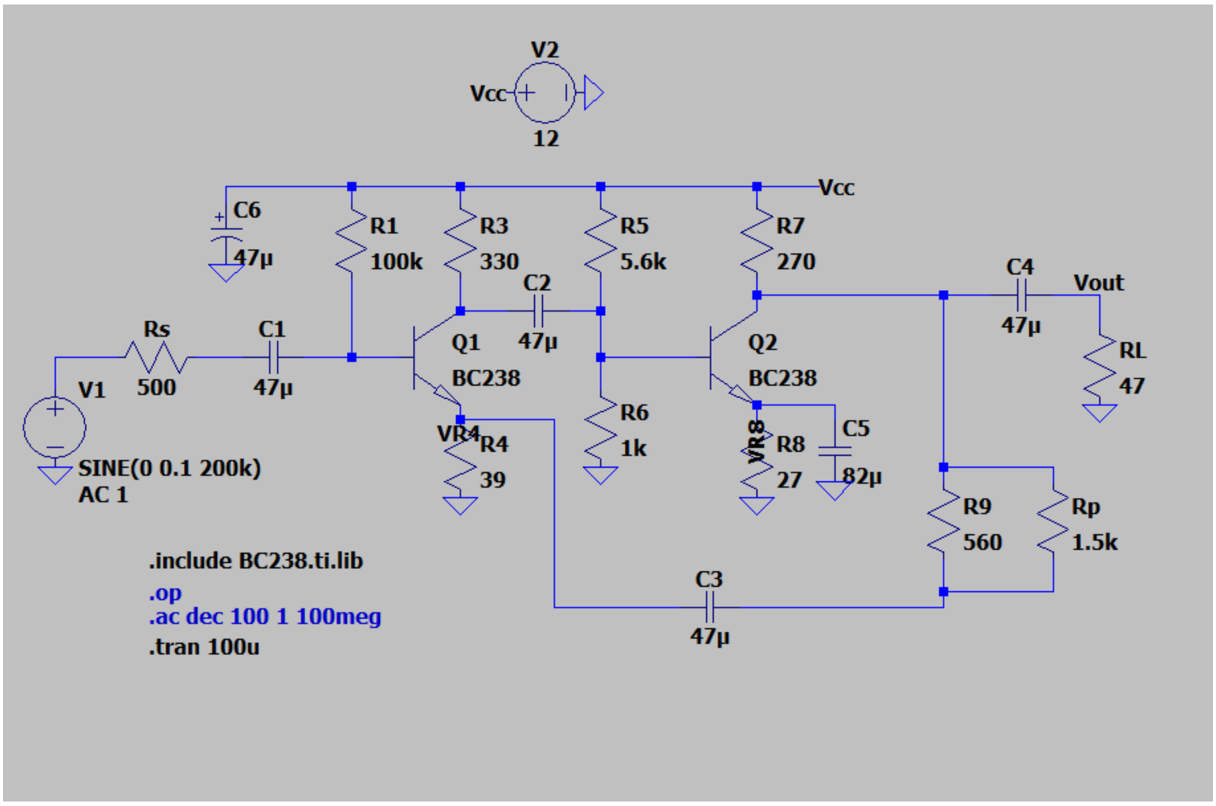


Figure 1: Designed Circuit

For the design, the following requirement were expected and students were asked the determine three values.

Show that

1. The current consumption is less than 70mA
2. The small-signal bandwidth is at least 2KHz-2MHz while the mid-band gain is 20dB±0.5dB (by AC analysis)
3. The harmonic content of the output voltage is better than −30dBc with 0.1V peak input signal at 200KHz.

Determine

4. The small-signal input impedance of the amplifier at 200KHz (the adjusted value of R_S in AC analysis until the voltage gain drops by 6dB compared to R_S=0)
5. The small-signal output impedance of the amplifier at 200KHz (the adjusted value of R_L in AC analysis until the voltage gain drops by 6dB compared to R_L=∞)
6. The phase margin of the open-loop system.

REQUIREMENT 1

--- Operating Point ---

V(n004):	0	voltage
V(n005):	4.34026e-14	voltage
V(n006):	1.84692	voltage
V(vcc):	12	voltage
V(n002):	2.71909	voltage
V(vr4):	1.10079	voltage
V(n003):	1.70712	voltage
V(n001):	2.53523	voltage
V(vr8):	0.950011	voltage
V(n007):	2.53523	voltage
V(vout):	5.60032e-15	voltage
Ic(Q1):	0.028124	device_current
Ib(Q1):	0.000101531	device_current
Ie(Q1):	-0.0282255	device_current
Ic(Q2):	0.0350547	device_current
Ib(Q2):	0.000130898	device_current
Ie(Q2):	-0.0351856	device_current
I(C1):	8.68051e-17	device_current
I(C6):	5.64e-16	device_current
I(C2):	-4.75627e-17	device_current
I(C3):	6.74185e-17	device_current
I(C5):	7.79009e-17	device_current
I(C4):	-1.19156e-16	device_current
I(Rs):	8.68051e-17	device_current
I(R1):	0.000101531	device_current
I(R3):	0.028124	device_current
I(R4):	0.0282255	device_current
I(R5):	0.00183801	device_current
I(R7):	0.0350547	device_current
I(R6):	0.00170712	device_current
I(R8):	0.0351856	device_current
I(R9):	4.8374e-17	device_current
I(Rl):	1.19156e-16	device_current
I(Rp):	1.80596e-17	device_current
I(V1):	8.68051e-17	device_current
I(Vsupply):	-0.0651182	device_current

Figure 2: DC Analysis Results

The current that goes through the supply voltage source dictates the consumed current and it is 65.12 mA < 70 mA, satisfying the following requirement.

1. The current consumption is less than 70mA

REQUIREMENT 2

2. The small-signal bandwidth is at least 2KHz-2MHz while the mid-band gain is 20dB±0.5dB (by AC analysis)

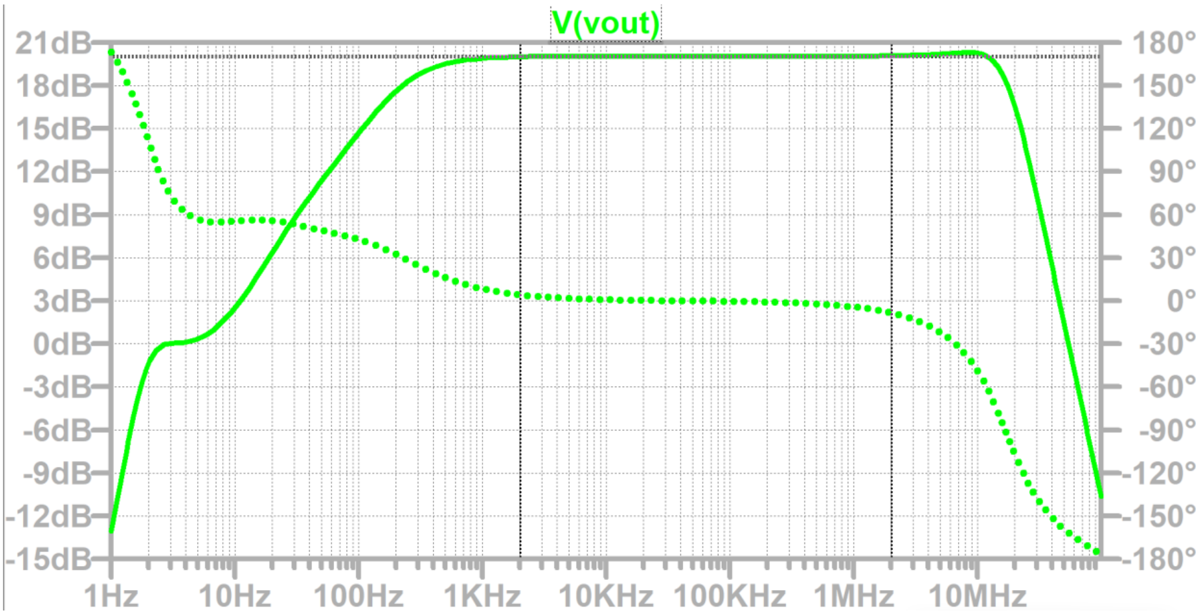


Figure 3: AC Analysis, Finding The Gain at 2 kHz and 2 MHz

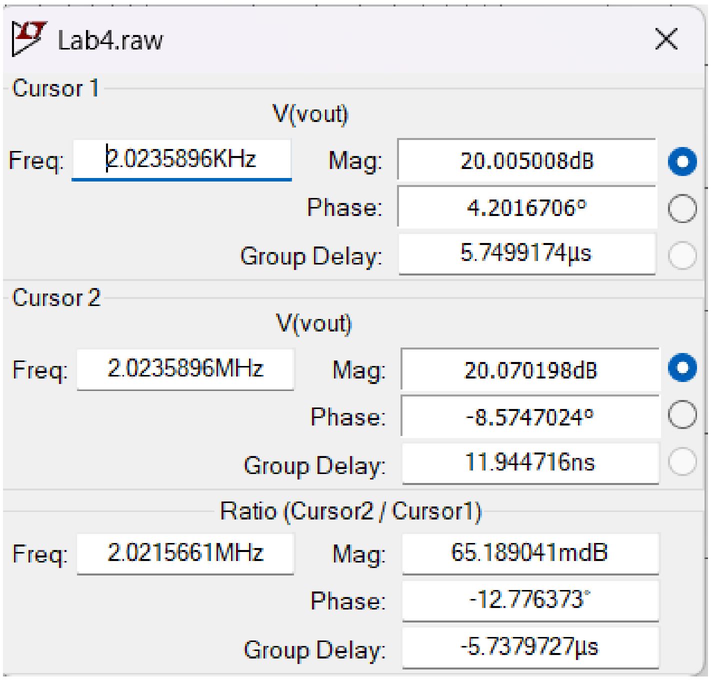


Figure 4: Gain at 2 kHz and 2 MHz

The bandwidth expands the given minimum range of 2 kHz to 2 MHz and the gain is 20.05 dB, in the range of 19.5-20.5 dB, satisfying the given requirement.

REQUIREMENT 3

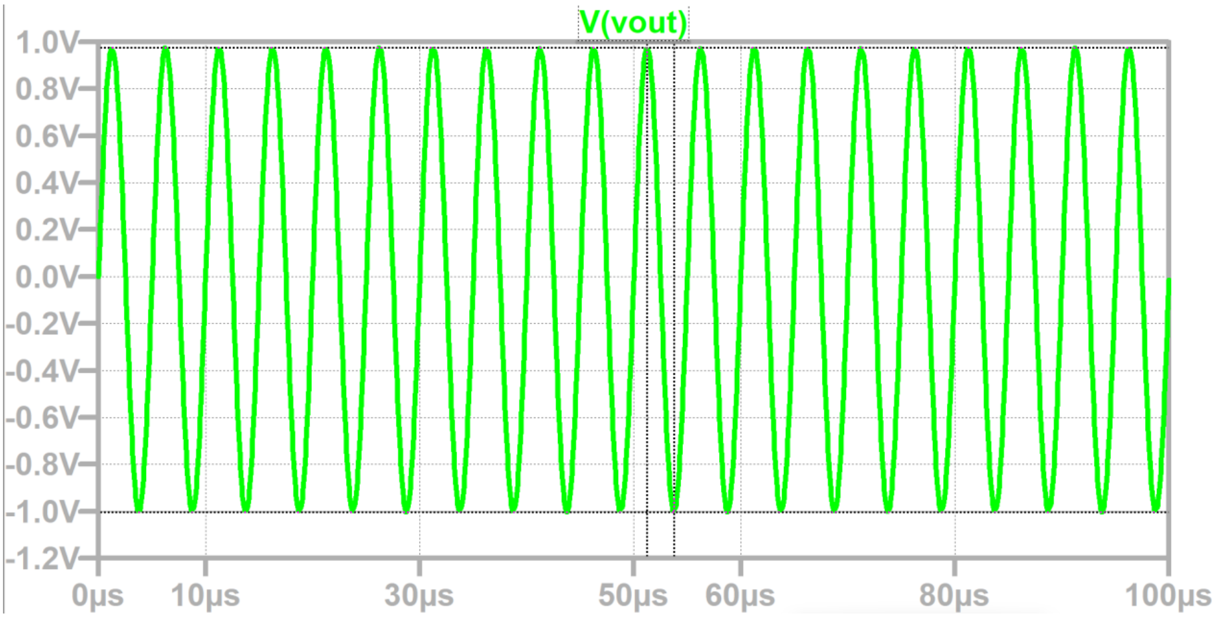


Figure 5: Vout with 0.1 Vpp, 200 kHz Input

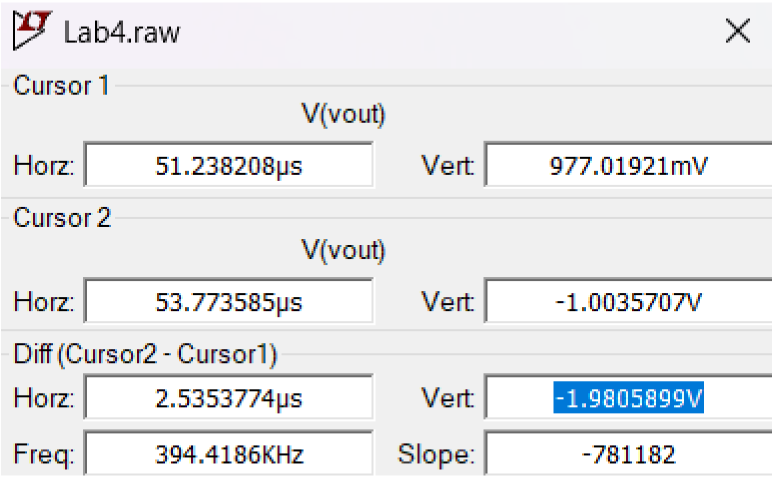


Figure 6: Vout is 2Vpp

Vout is 2 V peak to peak as desired.

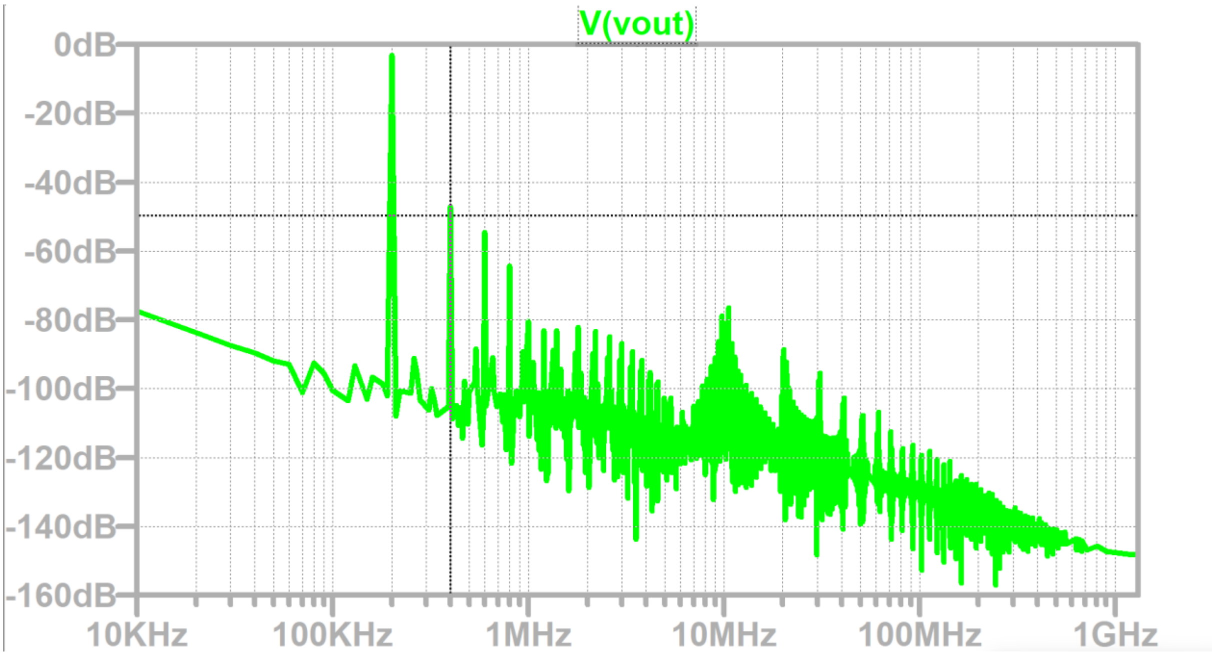


Figure 7: Vout FFT, 0.1 Vpp, 200 kHz Input

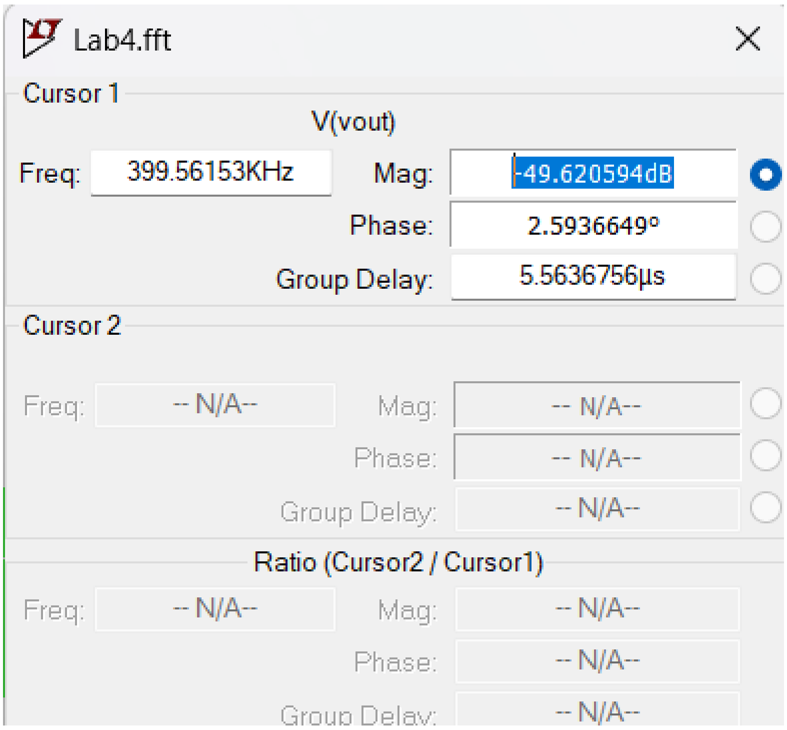


Figure 8: -49.62 dB at Highest Harmonic

The magnitude of the harmonic carrying the highest value is -49.62 dB, which is less than -30 dB at 0.1 Vpp, 200 kHz input, satisfying the given requirement.

VALUE TO DETERMINE – 1

4. The small-signal input impedance of the amplifier at 200KHz (the adjusted value of R_S in AC analysis until the voltage gain drops by 6dB compared to R_S=0)

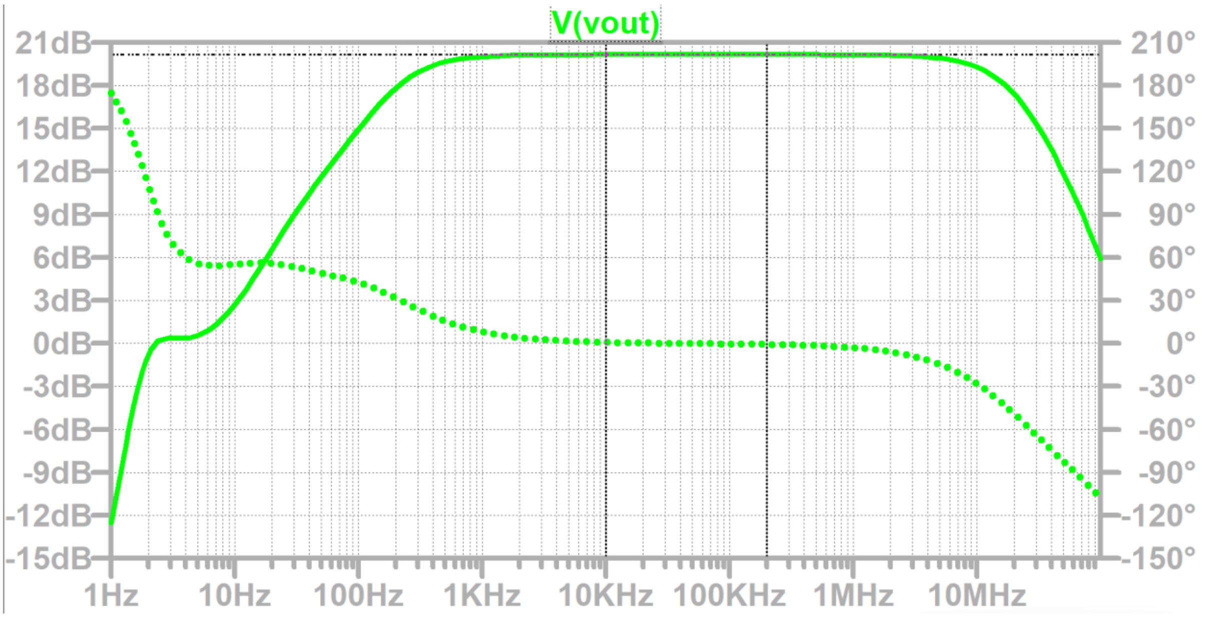


Figure 9: Source Resistance is 0

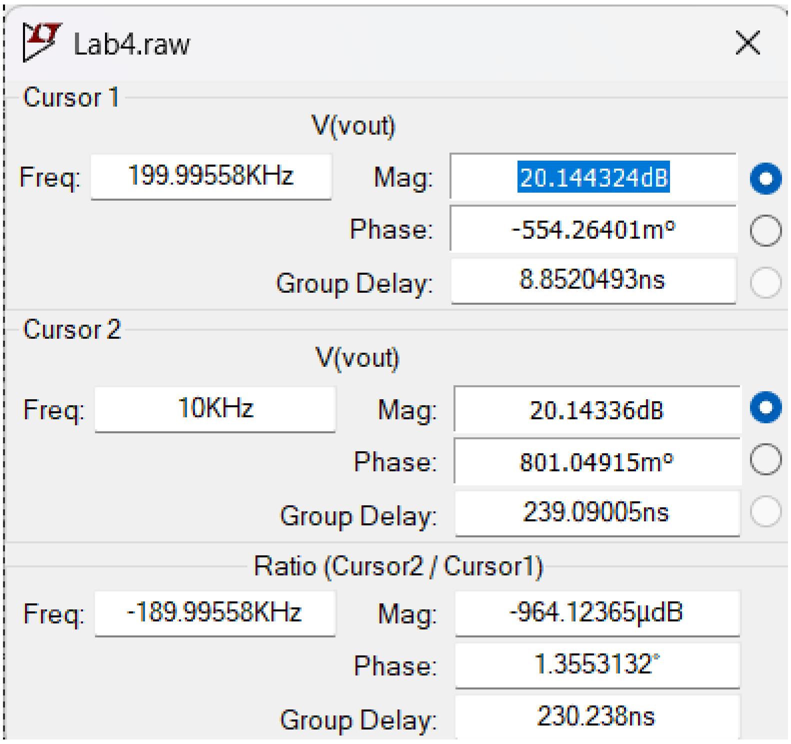


Figure 10: Gain at Zero Source Resistance

The gain is 20.14 dB at zero input resistance.

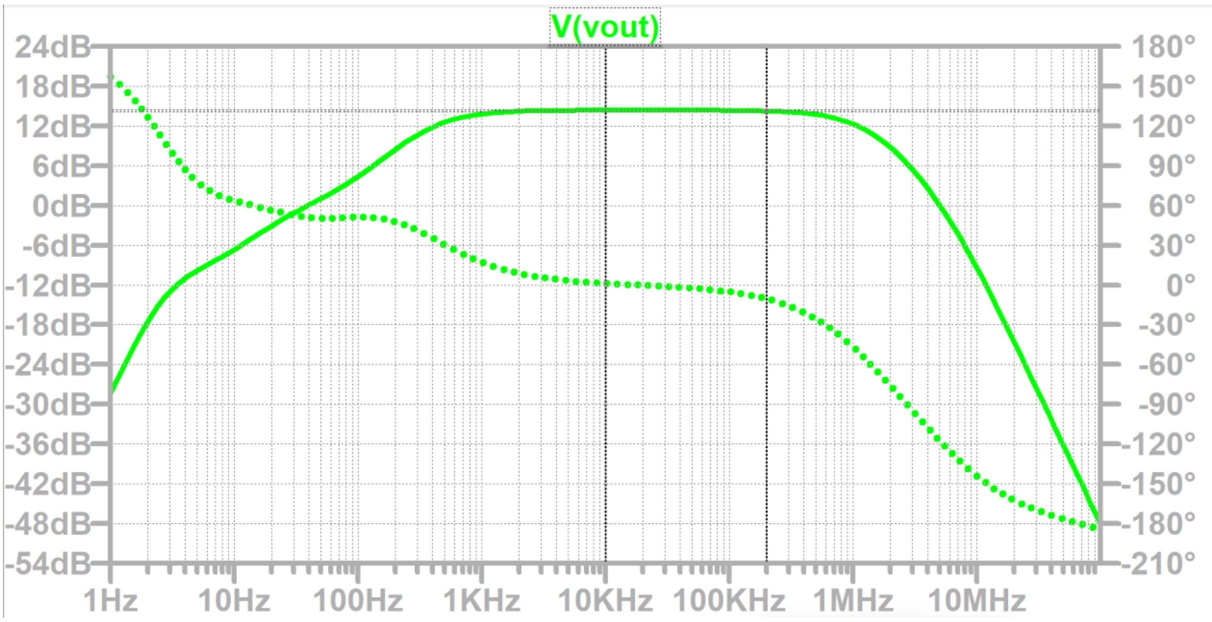


Figure 11: Vout with 39k Input Resistance

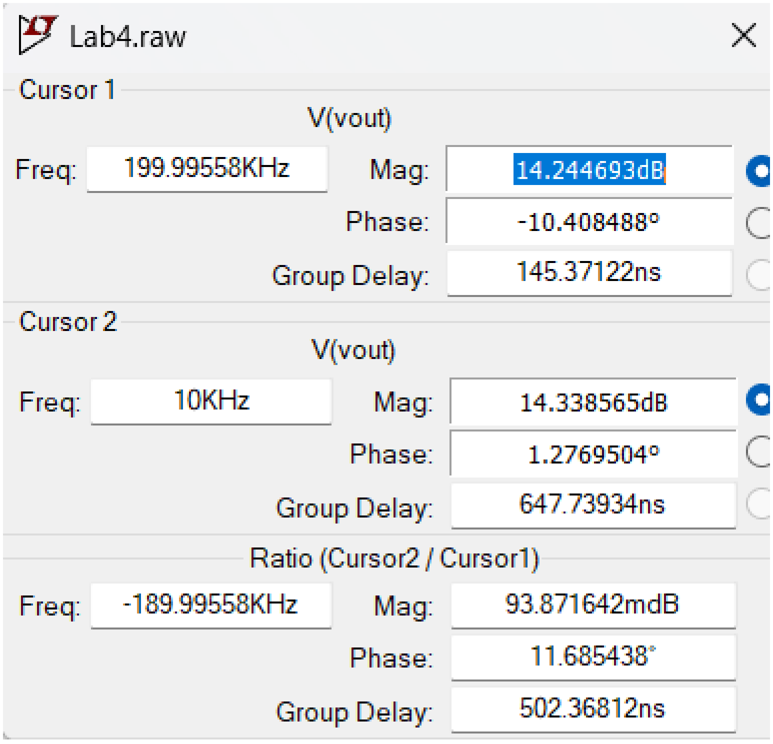


Figure 12: Gain is 14.24 dB with 39k Input Resistance

At 200 kHz, as the source resistance is adjusted from zero to 39k, the gain decreases from 20.14 dB to 14.24 dB, implying a 5.9 dB drop. The value found is 39 kiloohms.

VALUE TO DETERMINE – 2

5. The small-signal output impedance of the amplifier at 200KHz (the adjusted value of R_L in AC analysis until the voltage gain drops by 6dB compared to $R_L=\infty$)

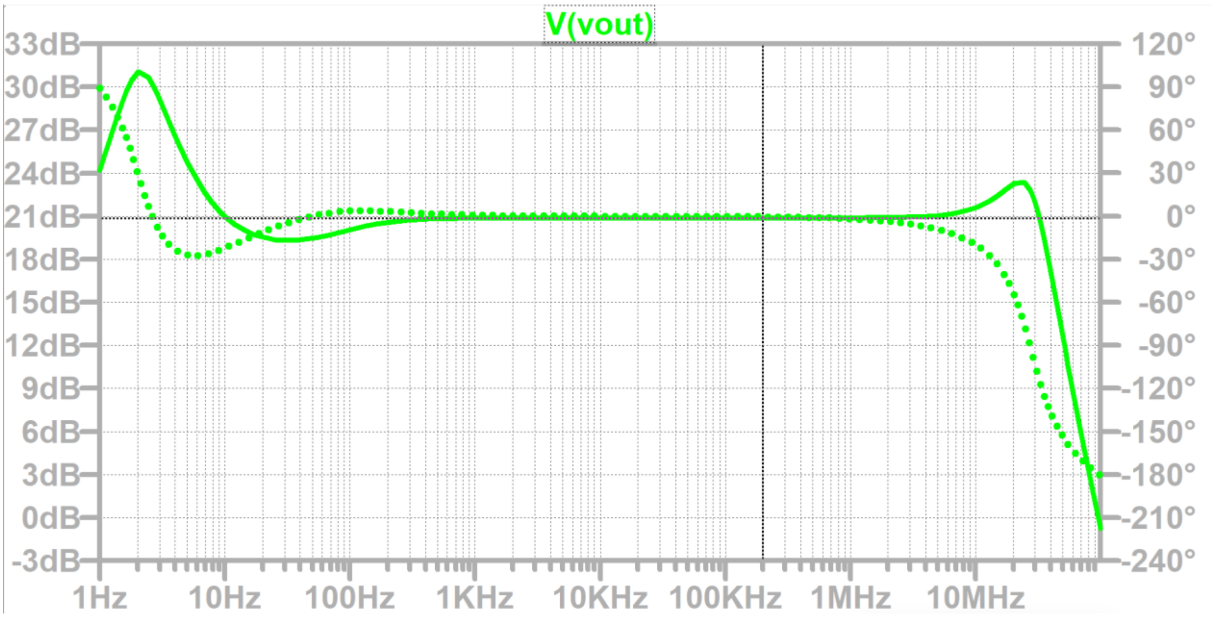


Figure 13: Gain With Infinite Load Resistance

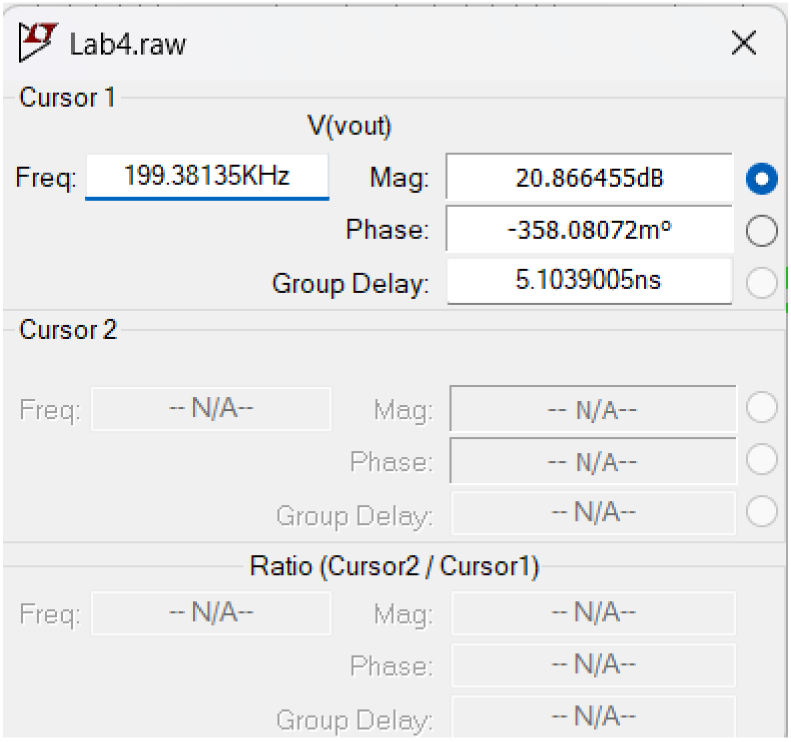


Figure 14: Gain With Infinite Load Resistance = 20.866 dB

The gain is 20.87 dB at infinite load resistance.

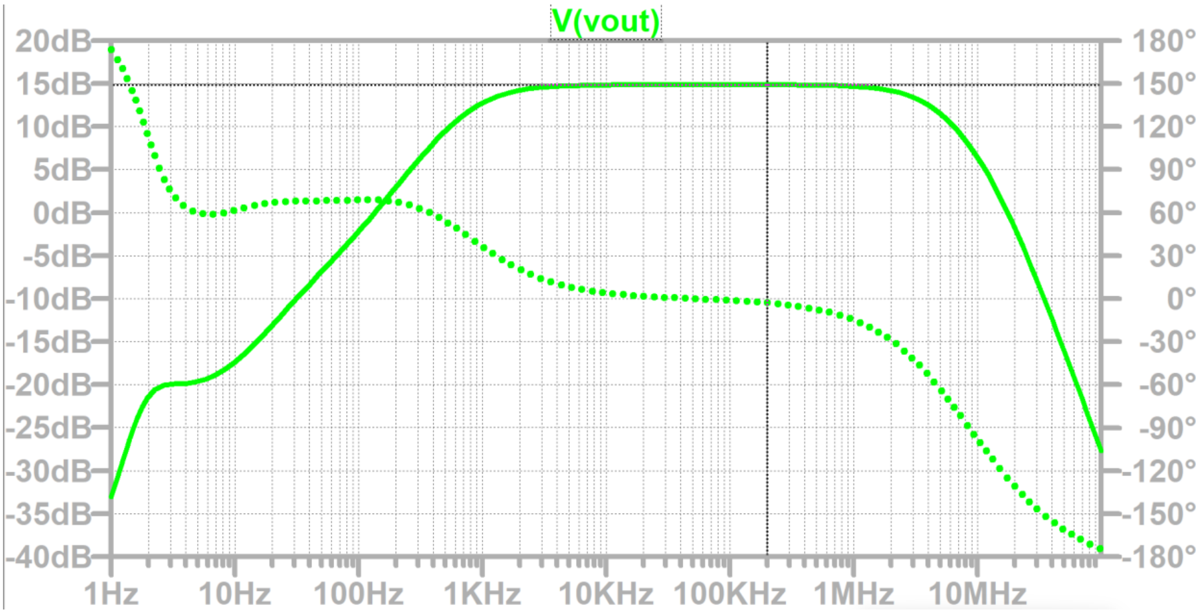


Figure 15: Gain With 4.7 Ohm Load Resistance

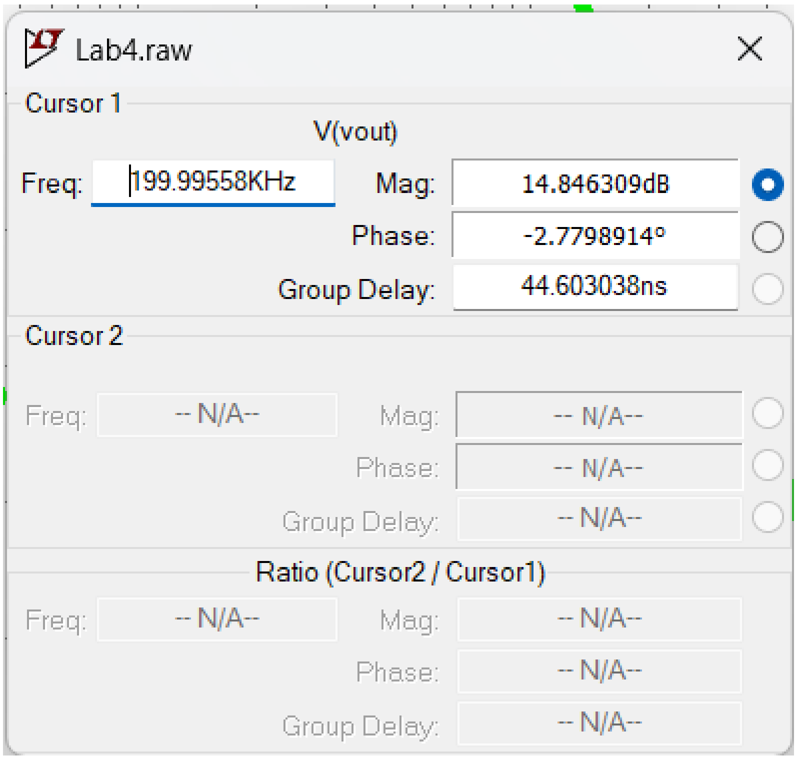


Figure 16: Gain With 4.7 Ohm Load Resistance = 14.85 dB

At 200 kHz, the gain changes from 20.86 dB to 14.85 dB as the load resistance changes from infinity to 4.7 Ohms. The value found is 4.7 Ohms.

VALUE TO DETERMINE – 3

6. The phase margin of the open-loop system.

The following design change is applied to find the phase margin.

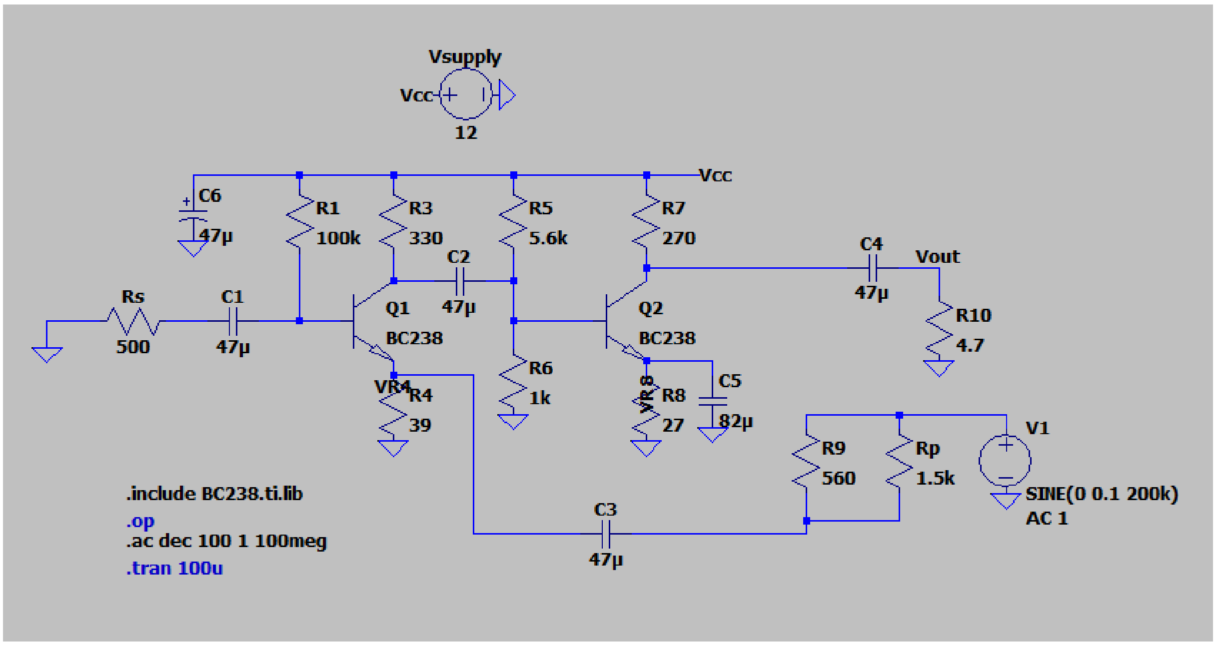


Figure 17: Changed Circuit

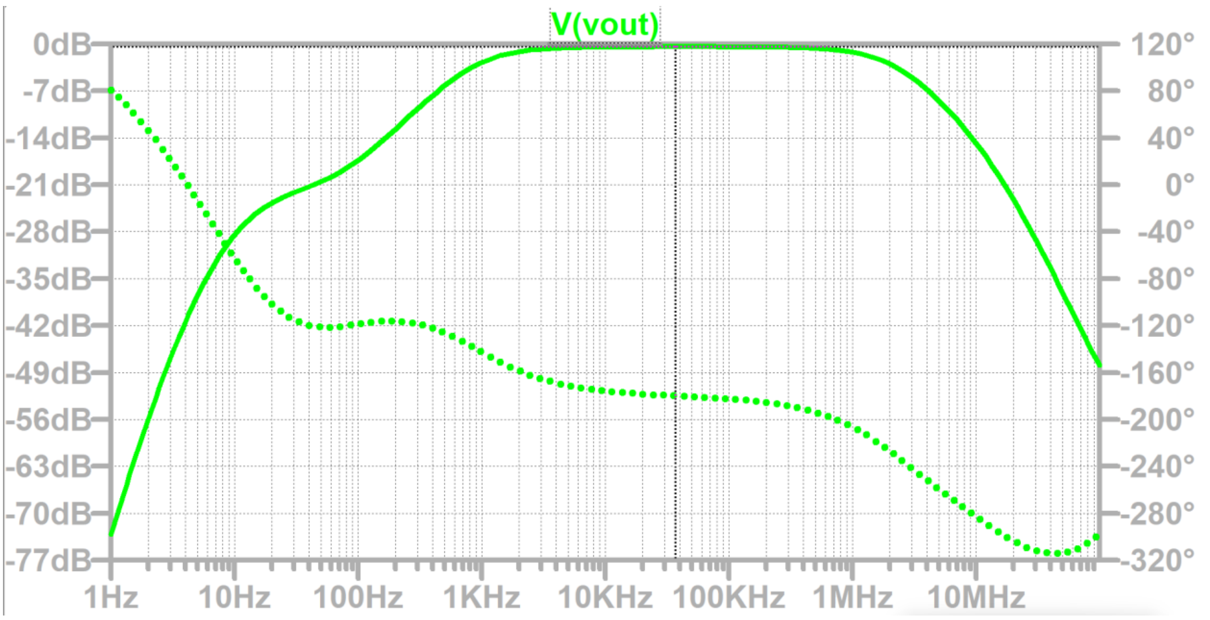


Figure 18: Vin is 1, Gain Graph

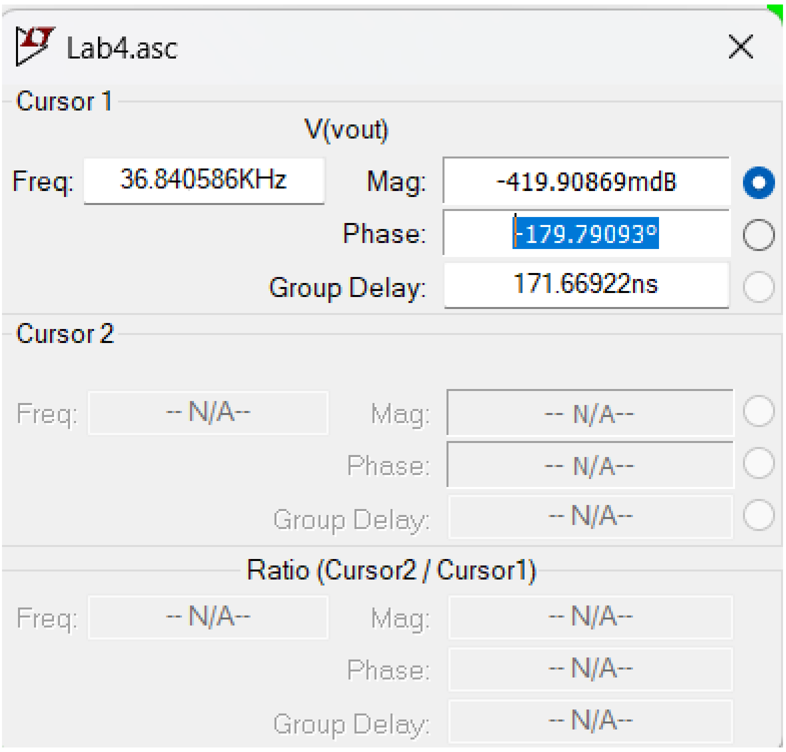
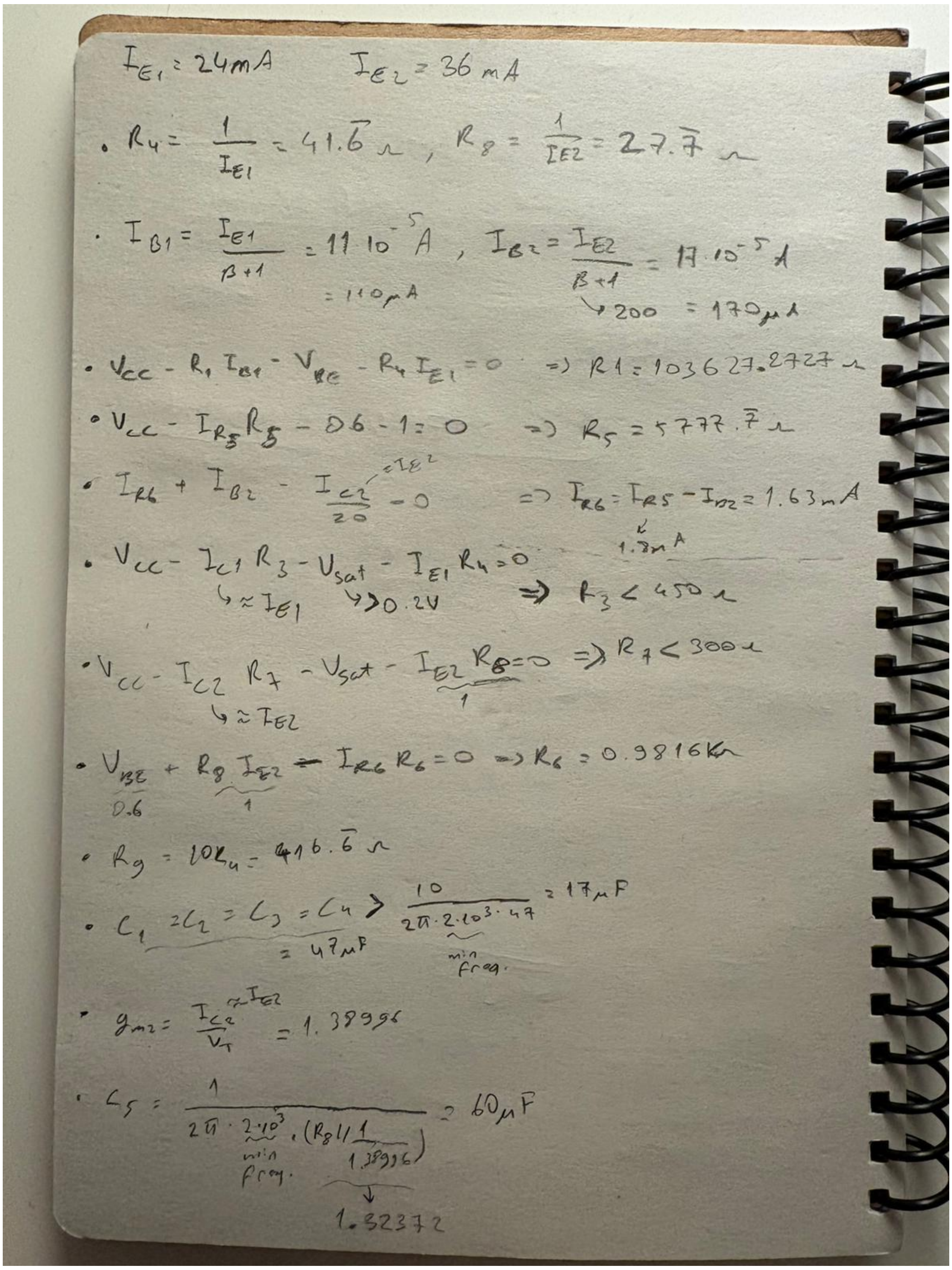


Figure 19: The Cursor at 0 Gain

The Phase Margin is calculated to be -179.79 + 360 = 180.21 degrees.

Hand Written Circuit Analysis For Finding Element Values



$I_{E1} = 24mA \qquad I_{E2} = 36\,mA$

- $R_4 = \frac{1}{I_{E1}} = 41.\bar{6}\,\Omega$, $R_8 = \frac{1}{I_{E2}} = 27.\bar{7}\,\Omega$
- $I_{B1} = \frac{I_{E1}}{\beta+1} = 11 \cdot 10^{-5} A = 110\mu A$, $I_{B2} = \frac{I_{E2}}{\beta+1} = 17 \cdot 10^{-5} A = 170\mu A$ ($\beta+1 \to 200$)
- $V_{CC} - R_1 I_{B1} - V_{BE} - R_4 I_{E1} = 0 \Rightarrow R1 = 103627.2727\,\Omega$
- $V_{CC} - I_{R5} R_5 - 0.6 - 1 = 0 \Rightarrow R_5 = 5777.\bar{7}\,\Omega$
- $I_{R6} + I_{B2} - \frac{I_{C2}}{20} = 0 \Rightarrow I_{R6} = I_{R5} - I_{B2} = 1.63\,mA$ ($I_{C2} \approx I_{E2}$, $1.8mA$)
- $V_{CC} - I_{C1} R_3 - V_{sat} - I_{E1} R_4 = 0 \Rightarrow R_3 < 450\,\Omega$ ($I_{C1} \approx I_{E1}$, $V_{sat} > 0.2V$)
- $V_{CC} - I_{C2} R_7 - V_{sat} - \underbrace{I_{E2} R_8}_{1} = 0 \Rightarrow R_7 < 300\,\Omega$ ($I_{C2} \approx I_{E2}$)
- $\underbrace{V_{BE}}_{0.6} + \underbrace{R_8 I_{E2}}_{1} - I_{R6} R_6 = 0 \Rightarrow R_6 = 0.9816 k\Omega$
- $R_9 = 10 R_4 = 416.\bar{6}\,\Omega$
- $\underbrace{C_1 = C_2 = C_3 = C_4}_{= 47\mu F} > \frac{10}{2\pi \cdot \underbrace{2 \cdot 10^3}_{\text{min freq.}} \cdot 47} = 17\mu F$
- $g_{m2} = \frac{I_{C2}}{V_T} = 1.38996$ ($I_{C2} \approx I_{E2}$)
- $C_5 = \frac{1}{2\pi \cdot \underbrace{2 \cdot 10^3}_{\text{min freq.}} \cdot \underbrace{(R_8 // \frac{1}{1.38996})}_{1.32372}} = 60\mu F$

Figure 20: Calculations Regarding Schematic on Manual

Conclusion

In the fourth lab, the students designed a wide band amplifier with a desired kind of feedback by satisfying three requirements. The final circuit was then inspected to determine three values. All requirements were satisfied and this lab was useful in terms of totally grasping amplifiers using BJTs.