Properties of the Differential Amplifier

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CO-526-B - Electronics Lab

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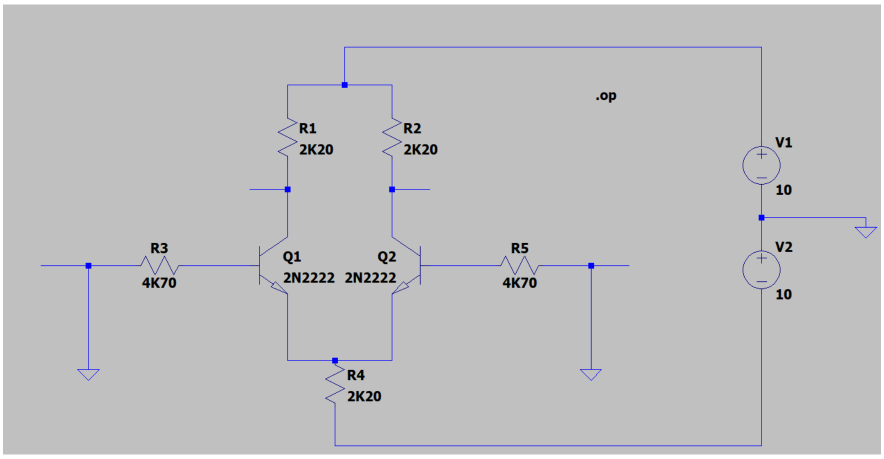
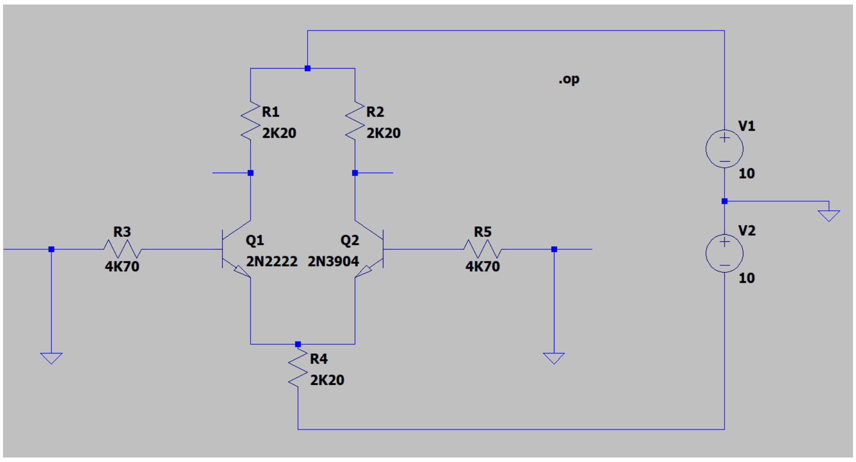
24/11/2024

1 Introduction - Prelab

1.1 Simulation of a Differential Amplifier

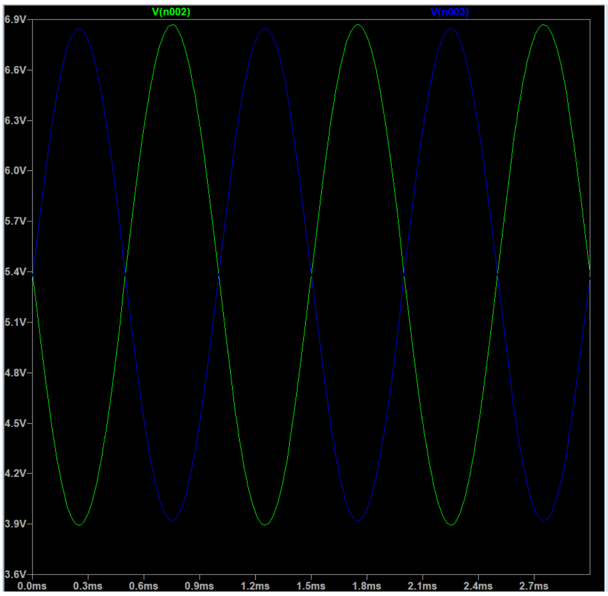
1. 

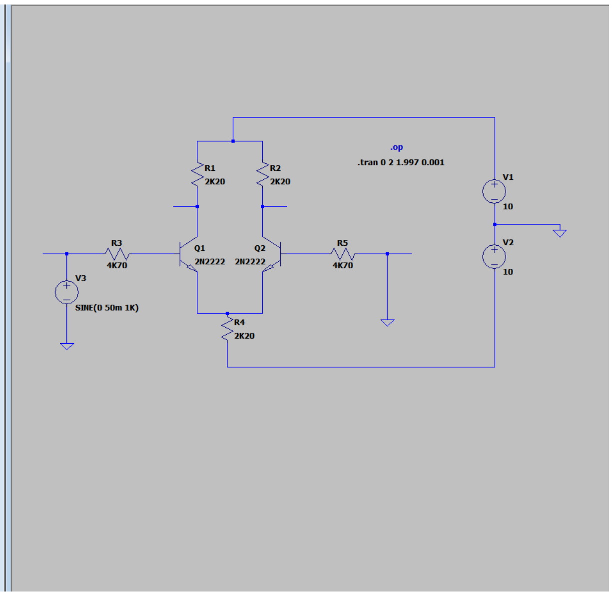
Measured voltages and currents:
V_{BE} = -47.09 - (-720.71) = 767.8mV, V_C = 5.382V, I_C = 2.099mA, I_E = 2.109mA, I_{RE} = 4.219mA.



By changing one transistor the V_{BE}, V_C, I_C, I_E values are not symmetric anymore (ex.: V_C(Q1) = 5.911V, V_C(Q2) = 4.837V), therefore the circuit cannot work properly.

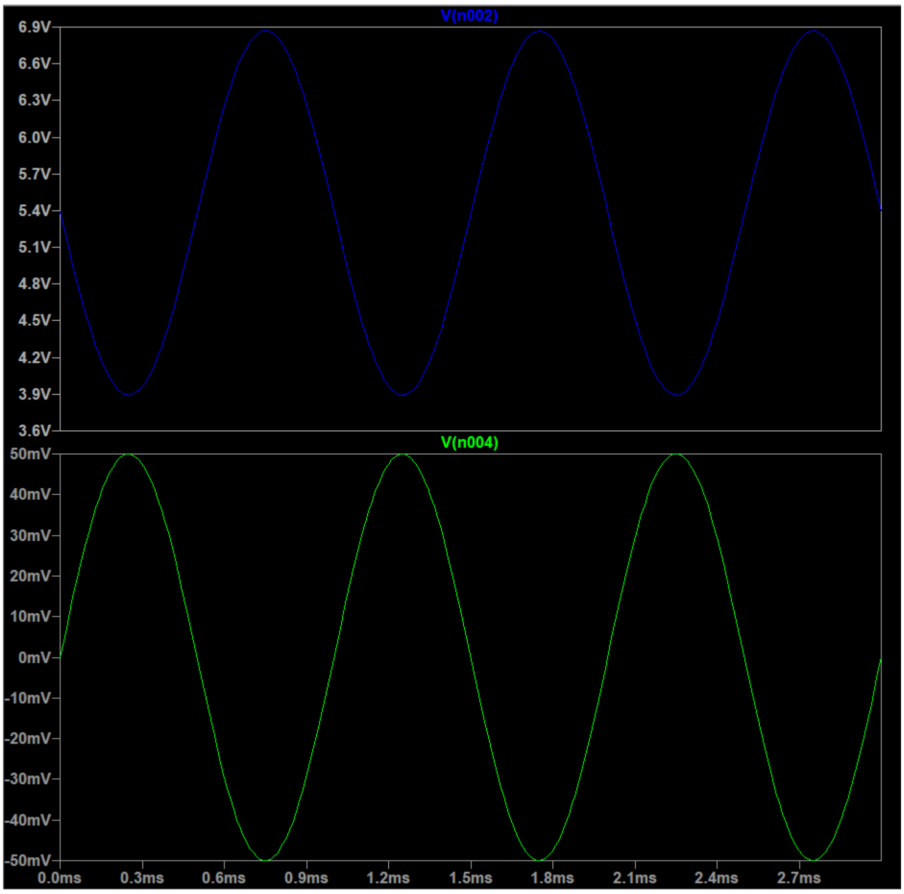
2. **Single ended input analysis**





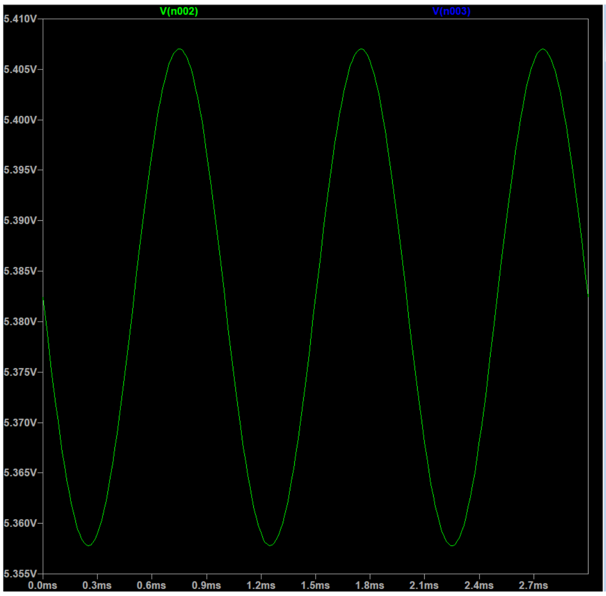
Green line: V_C(Q1), blue line: V_C(Q2). (peak to peak: 2.923V)

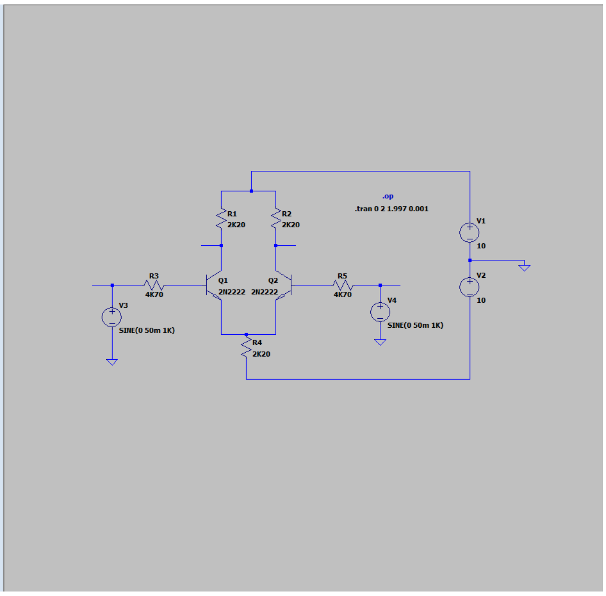
To calculate A_{Vdiff} I need V_{od} and V_{id}.



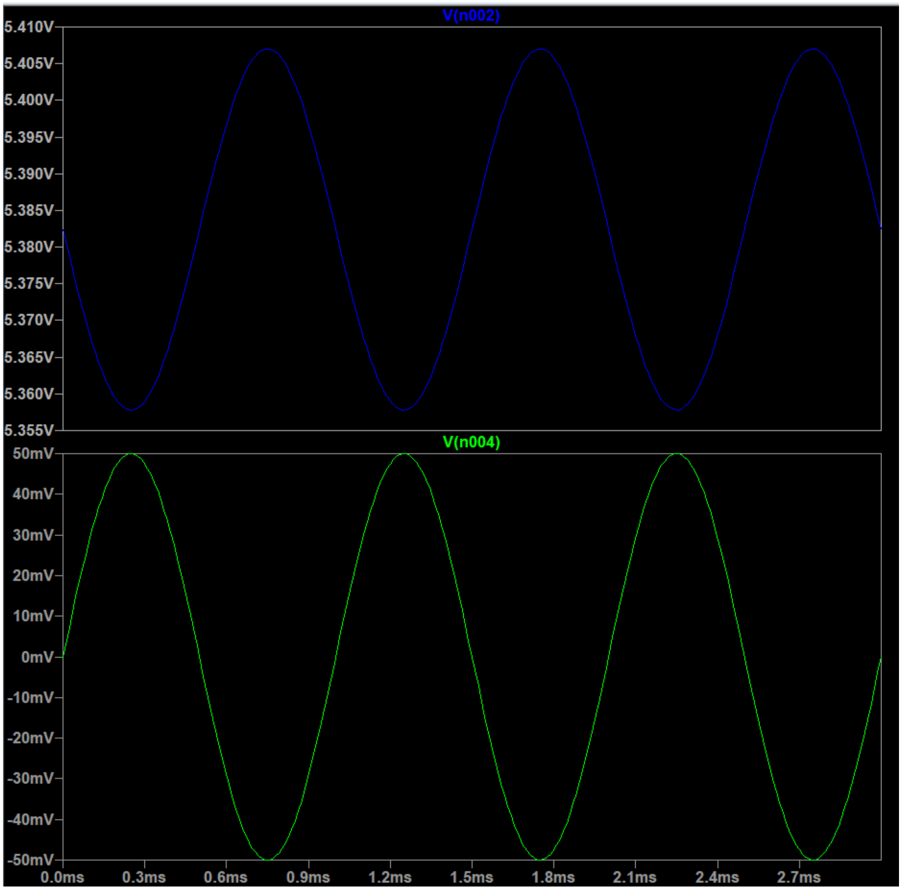
Top pane: V_{o1}, bottom pane: V_{i1}
$V_{id} = V_{i1} - V_{i2} = 100$mV peak to peak
$V_{od} = V_{o1} = 3$V peak to peak
$A_{Vdiff} = 20log(\frac{V_{od}}{V_{id}})$= 29.5 dB.

3. **Common mode input analysis**





V_C(Q1) and V_C(Q2) are overlapping. (peak to peak: 49.17mV).
To calculate A_{Vcm} I need V_{oc} and V_{ic}.



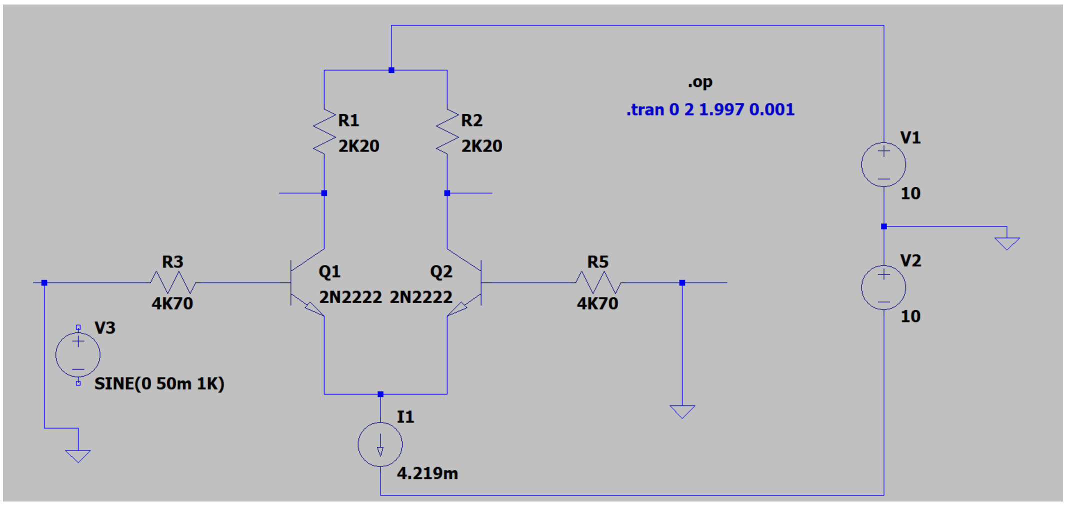
Top pane: V_{o1}, bottom pane: V_{i1}

$V_{ic} = (V_{i1} + V_{i2})/2 =$ 100mV peak to peak
$V_{oc} = V_{o1} =$ 49.18mV peak to peak
$A_{Vcm} = 20log(\frac{V_{oc}}{V_{ic}})$= -6.16 dB.

4. **Common mode rejection**

$CMRR = 20log(\frac{A_{Vdiff}}{A_{Vcm}})$= 35.7dB.
current source: 4.219 from top to bottom

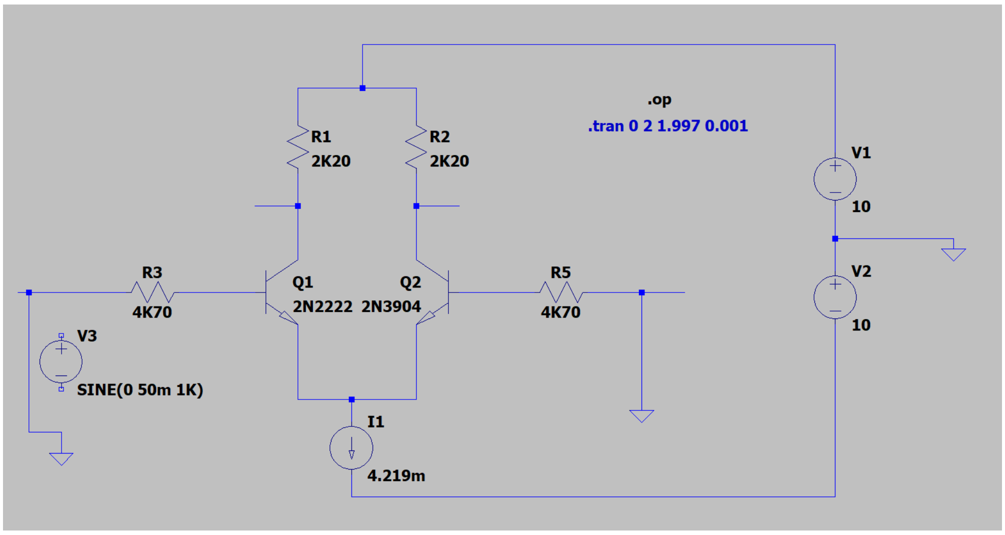
5. **Replacing R4 by equivalent current source**



6. **Analyses using the current source**

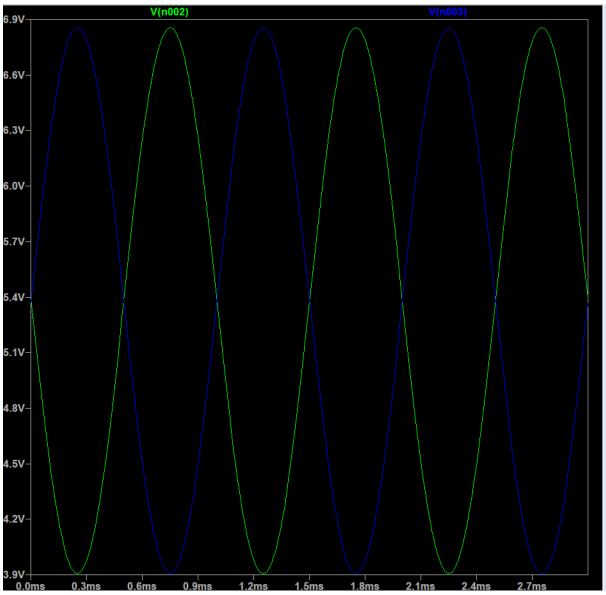
   (a) **DC operation point analysis**

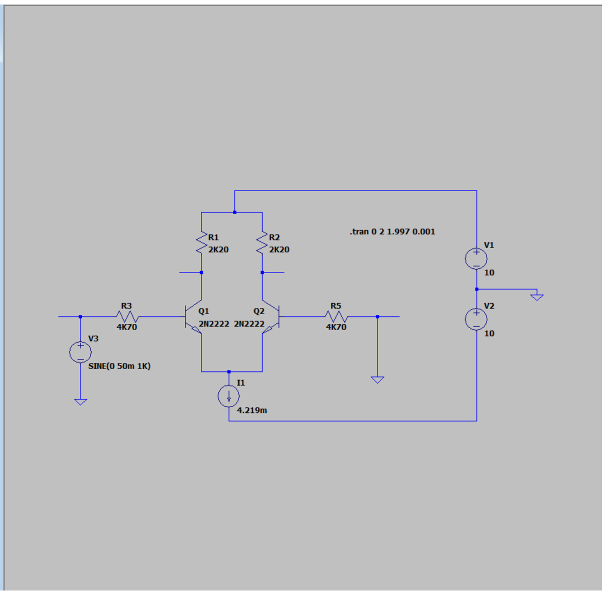
V_{BE} = -47.11 - (-720.74) = 767.85mV, V_C = 5.381V, I_C = 2.099mA, I_E = 2.109mA, I_{RE} = 4.219mA. (current source)



By changing one transistor the V_{BE}, V_C, I_C, I_E values are not symmetric anymore (ex.: V_C(Q1) = 5.913V, V_C(Q2) = 4.841V), therefore the circuit cannot work properly.

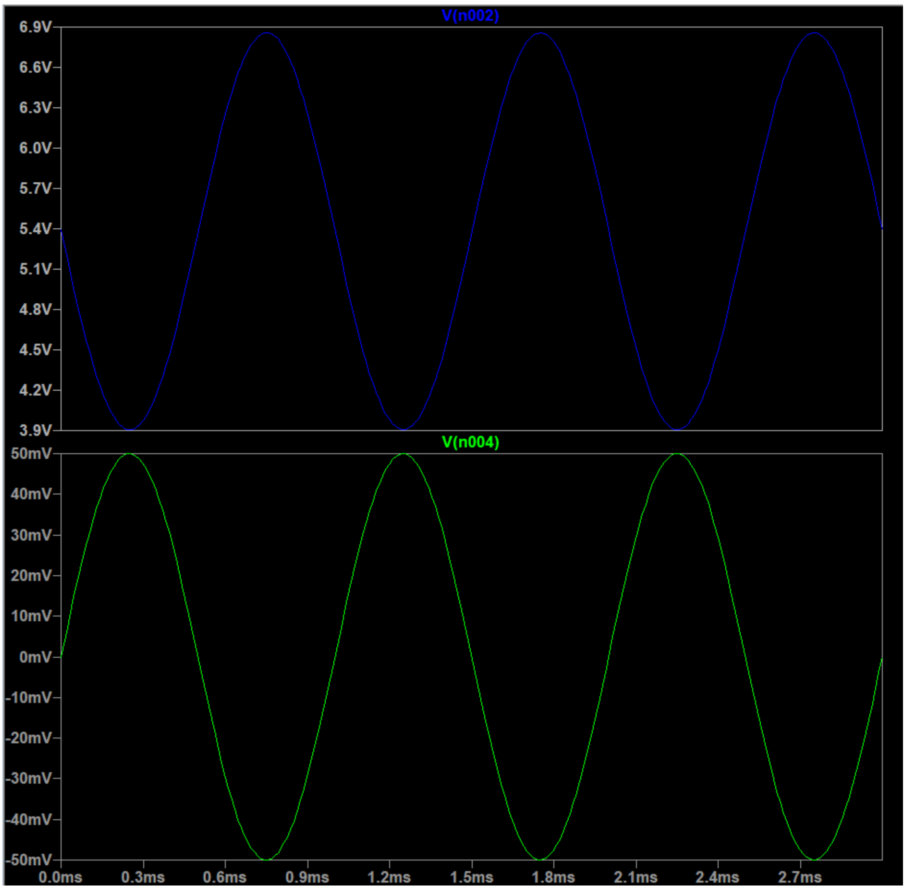
(b) **Single ended input analysis**





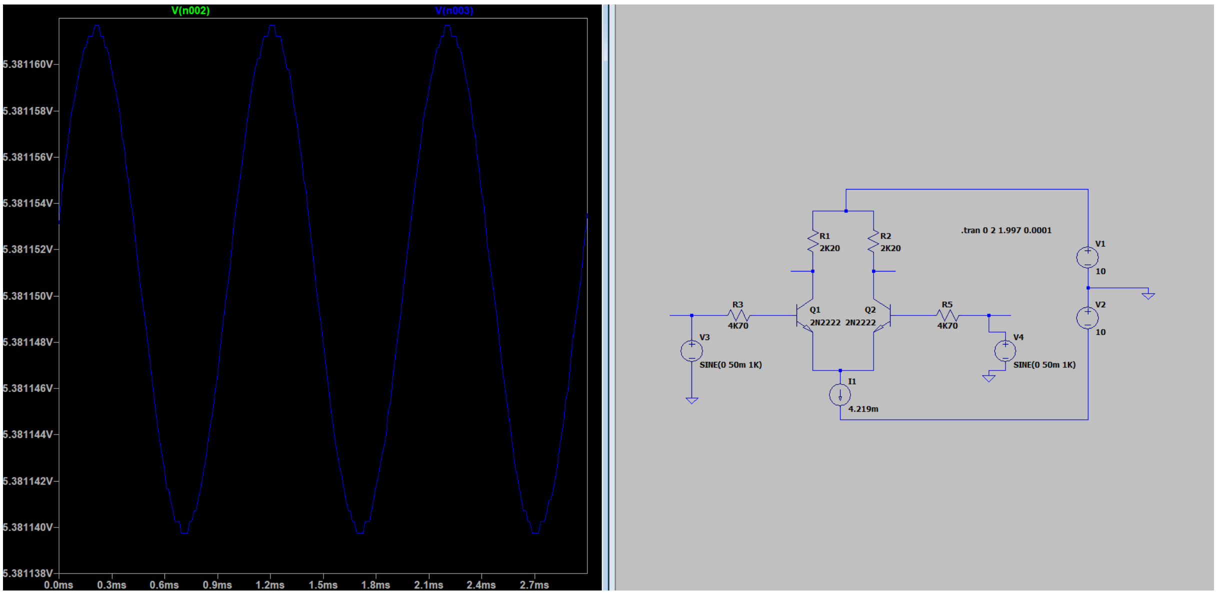
Green line: V_C(Q1), blue line: V_C(Q2). (peak to peak: 2.95V)

To calculate A_{Vdiff} I need V_{od} and V_{id}.



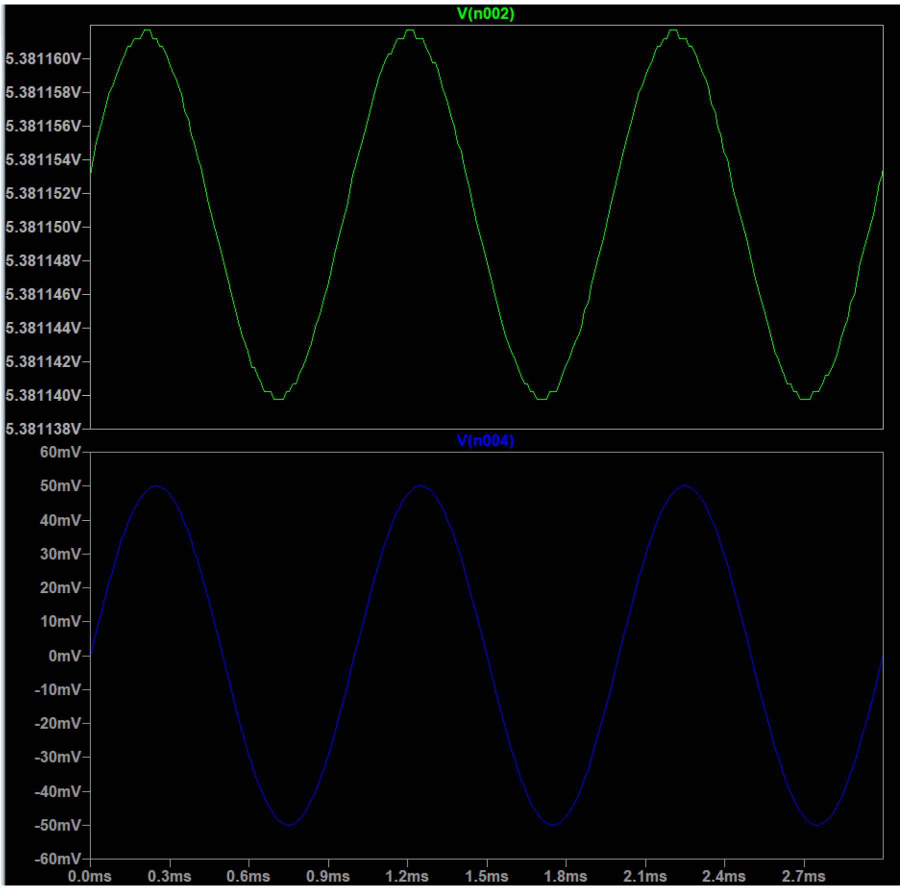
Top pane: V_{o1}, bottom pane: V_{i1}
$V_{id} = V_{i1} - V_{i2} = 100$mV peak to peak
$V_{od} = V_{o1} = 2.95$V peak to peak
$A_{Vdiff} = 20log(\frac{V_{od}}{V_{id}})$= 29.4 dB.

(c) **Common mode input analysis**



V_C(Q1) and V_C(Q2) are overlapping. (peak to peak: 21.93μV).

To calculate A_{Vcm} I need V_{oc} and V_{ic}.



Top pane: V_{o1}, bottom pane: V_{i1}

$V_{ic} = (V_{i1} + V_{i2})/2 = 100$mV peak to peak
$V_{oc} = V_{o1} = 21.93\mu$V peak to peak
$A_{Vcm} = 20log(\frac{V_{oc}}{V_{ic}})$= -73.28 dB.

(d) **Common mode rejection**

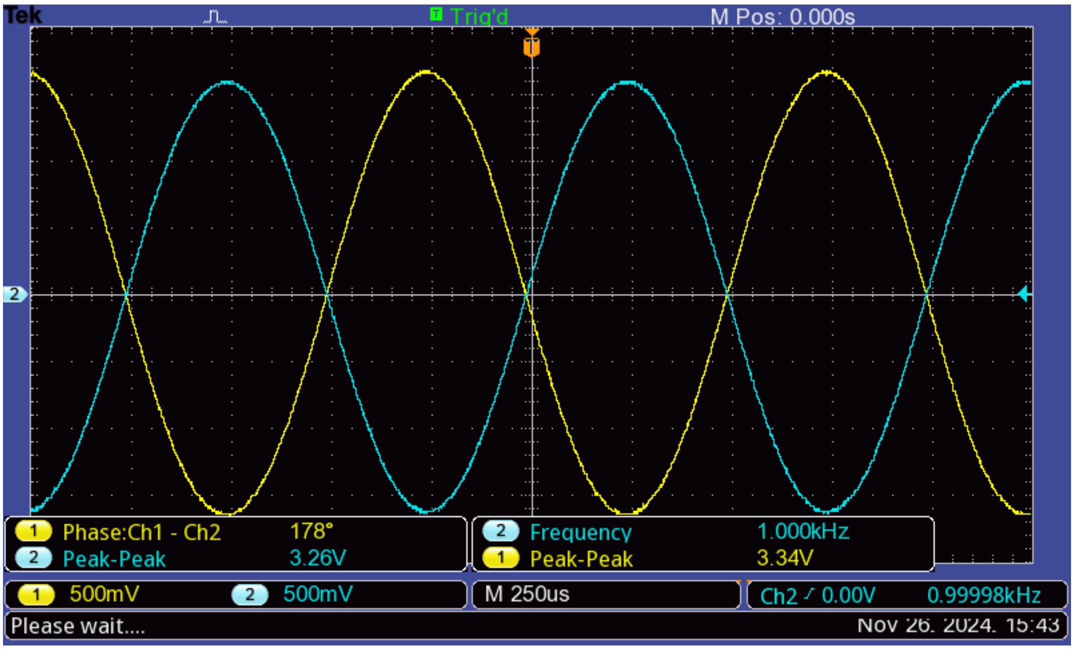
$CMRR = 20log(\frac{A_{Vdiff}}{A_{Vcm}})$= 102.6dB.

2 Experimental Set-up and Results

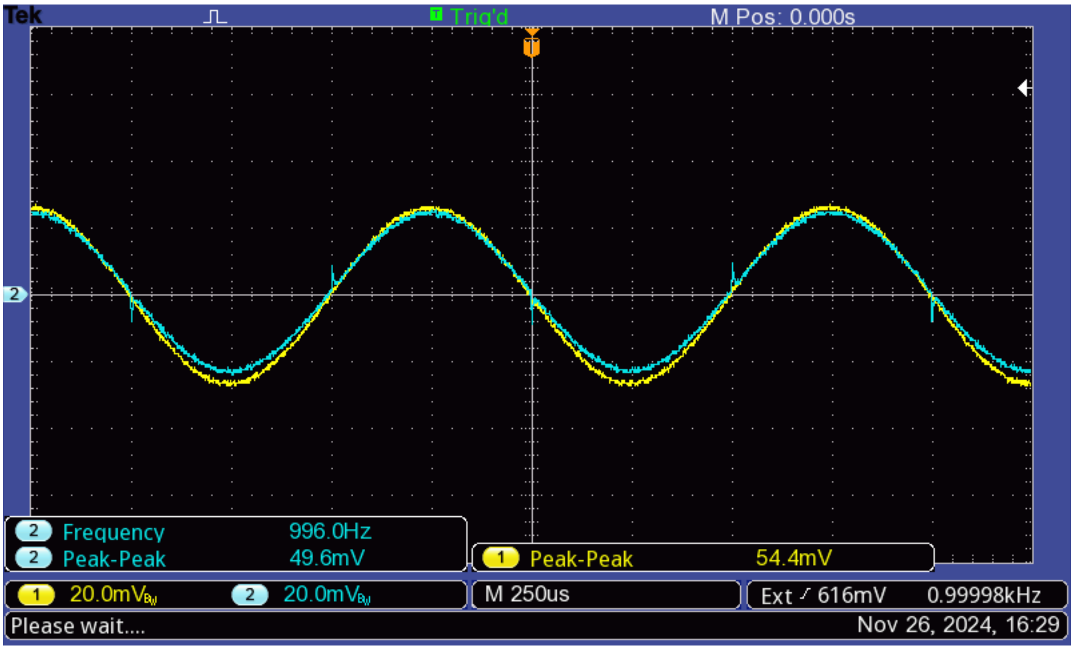
2.1 Differential amplifier using a fixed emitter resistor

1. COMPARE DC VALUES
2. **CMRR calculation**

Output voltage in single ended mode:



Output voltage in common mode:



Since the input is 100mV peak to peak

$V_{vdm} = 20log\frac{3300}{100}$ = 30.4dB

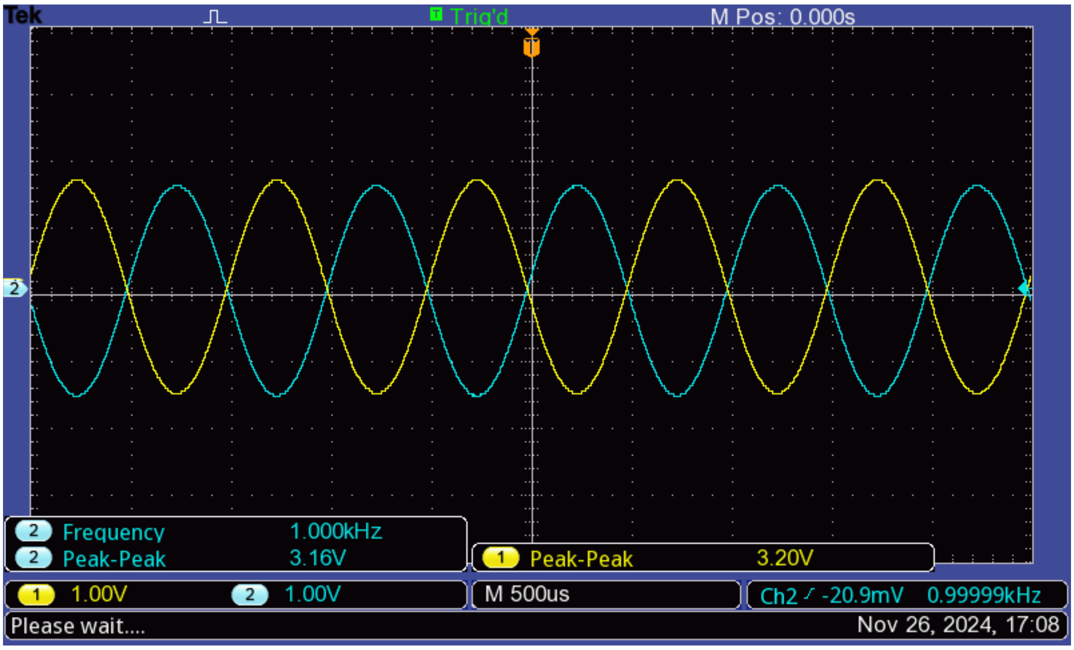
$V_{vcm} = 20log\frac{51.5}{100}$ = -5.76dB

CMRR $= 20log\frac{V_{vdm}}{V_{vcm}} = \frac{\frac{3300}{100}}{\frac{51.5}{100}}$ = 36.1dB

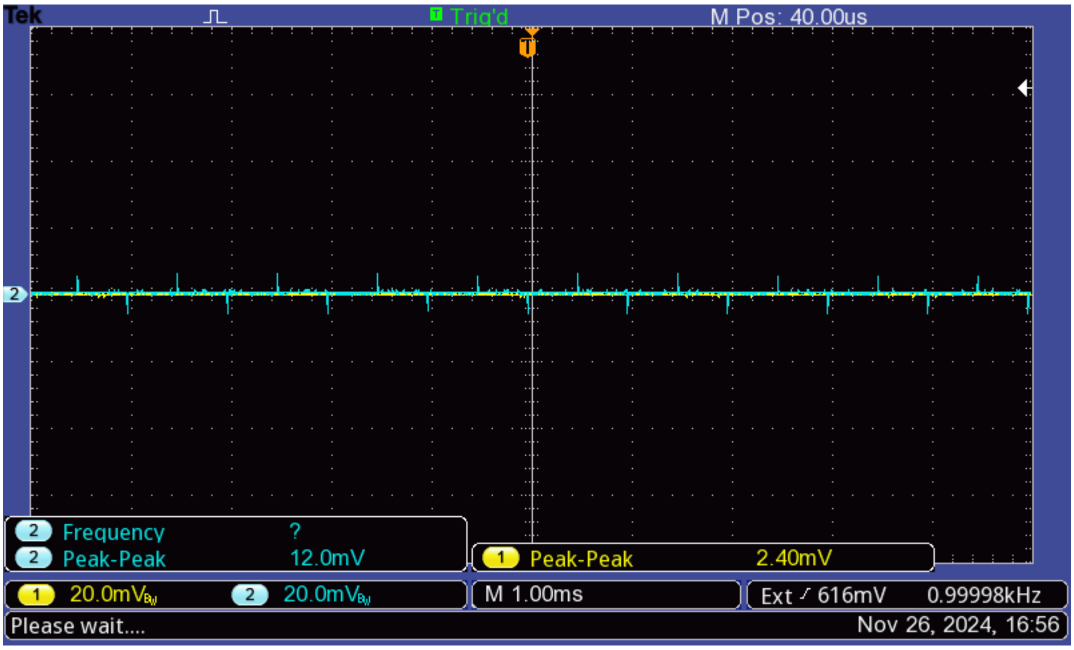
2.2 Differential amplifier using a current source

1. COMPARE DC VALUES
2. **CMRR calculation**

   Output voltage in single ended mode:



   Output voltage in common mode:



   The output voltage in common mode is too small to be precisely measured by the oscilloscope, for the calculation I'll use the simulated value instead (21.93μV peak to peak).

   Since the input is 100mV peak to peak

   $V_{vdm} = 20log\frac{3180}{100}$ = 30.05dB

   $V_{vcm} = 20log\frac{0.0219}{100}$ = -73.2dB

   CMRR $= 20log\frac{V_{vdm}}{V_{vcm}} = \frac{\frac{3180}{100}}{\frac{0.0219}{100}}$ = 83.2dB

3. **Performance comparison**

While using a fixed emitter resistor the differential voltage gain is almost the same as when using a current source (30.4dB vs 30.5dB), the common mode rejection ratio is around 224 times bigger when using a fixed current source (36.1dB vs 83.2dB).

3 Lab 3 Prelab

3.1 Biasing of Bipolar Junction Transistor

1. **Calculations**

$V_{R1}+V_B=20V$

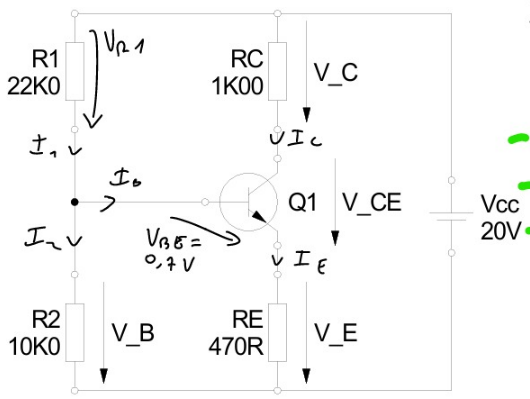
$I_C=150\,I_B$

$I_E=I_C+I_B$

$V_B=20\cdot\frac{R_2}{R_2+R_1}=6,23V$

$V_E=V_B-V_{BE}=5,55V$

$I_E=\frac{V_E}{R_E}=11,8mA$



$\begin{cases} I_C=150\,I_B \\ I_C+I_B=11,8mA \end{cases}$

$151\,I_B=11,8mA \rightarrow I_B=78,1\mu A$

$I_C=150\,I_B \rightarrow 11,72mA$

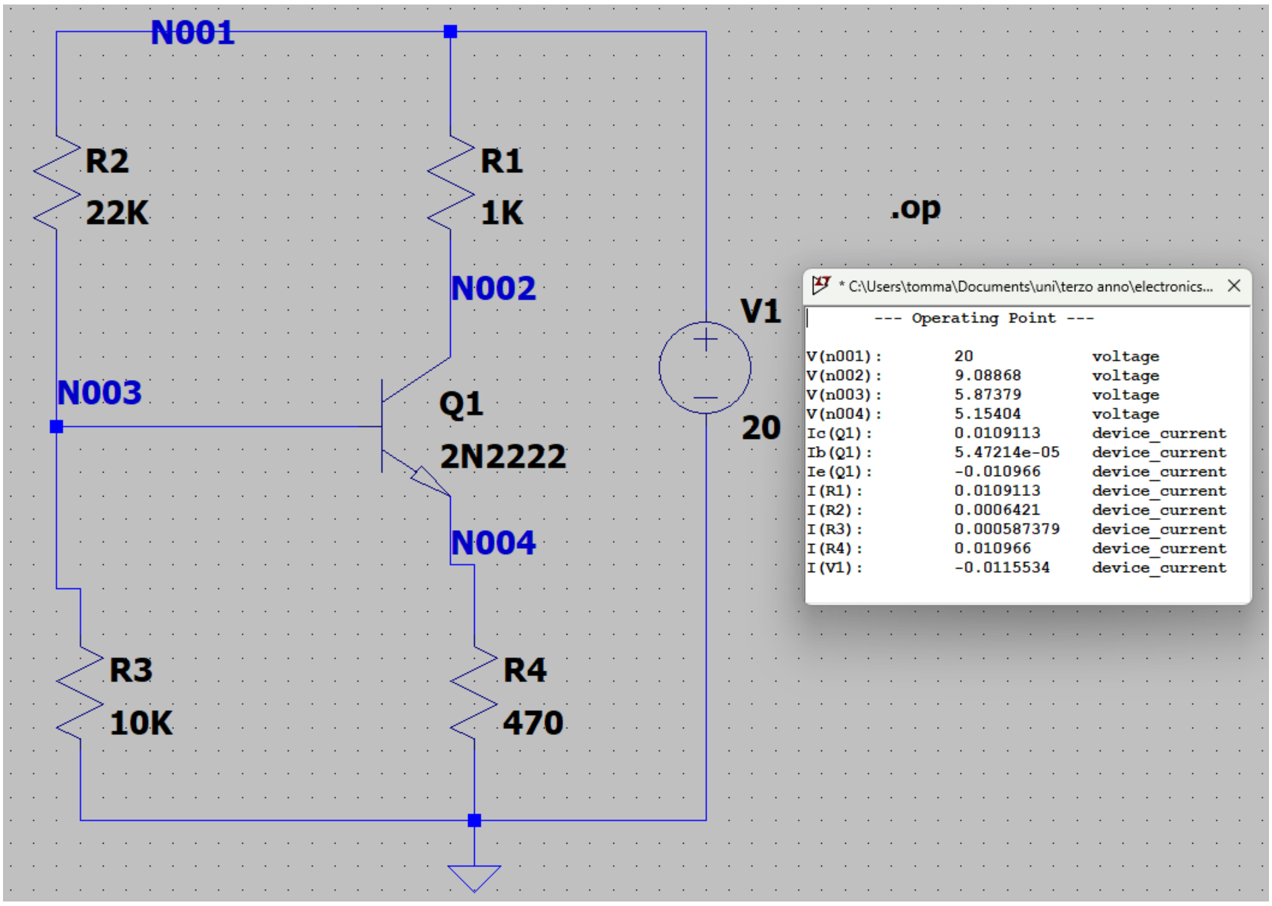
$V_C=I_C R_C=11,72V$

$V_{CE}=V_{CC}-V_C-V_E=2,73V$

$\beta=150$ and $V_{BE}=0.7\,\text{V}$

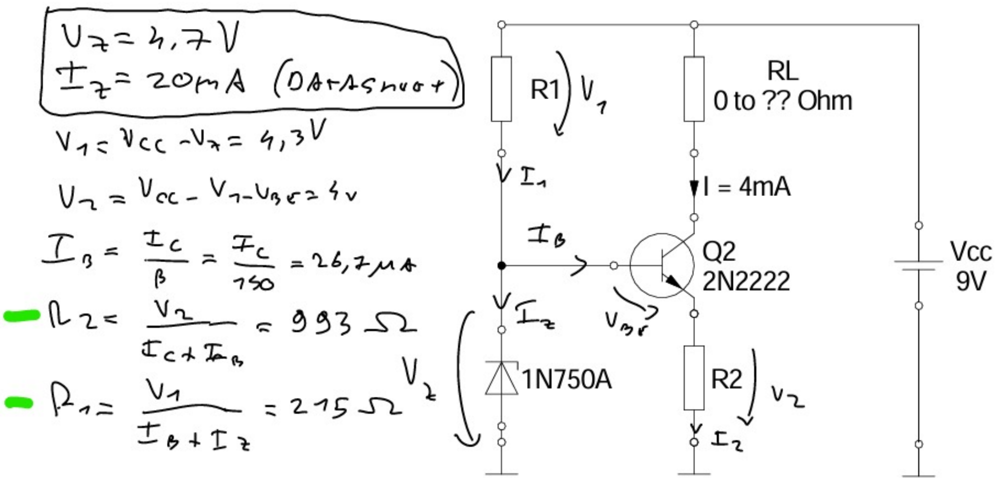
1. (a) Calculate V_B, V_E, V_{CE}, and V_C.
   (b) Calculate I_B, I_E, and I_C.

LTSpice simulation



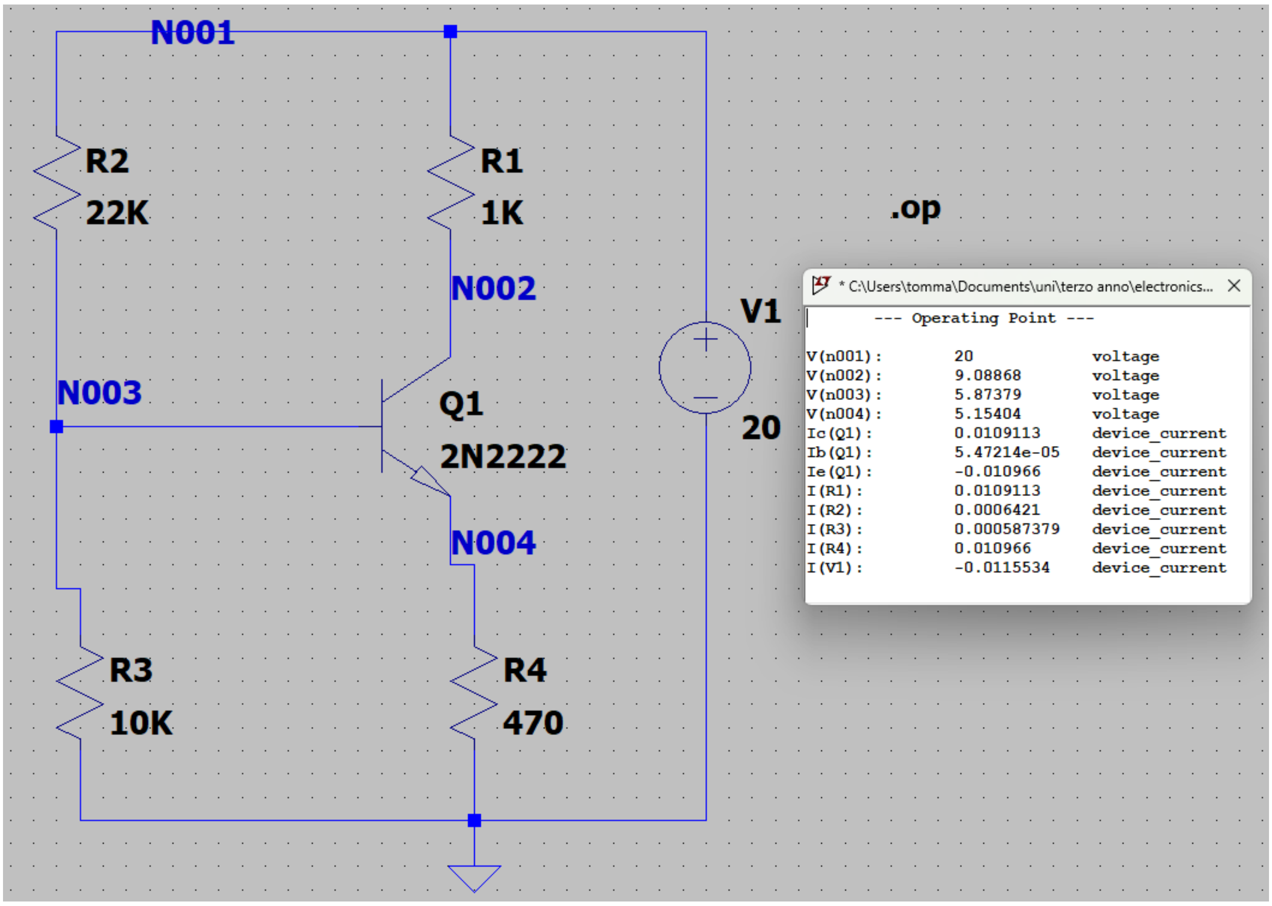
3.2 Constant Current Source

1. **Calculations and simulation on LTSpice**



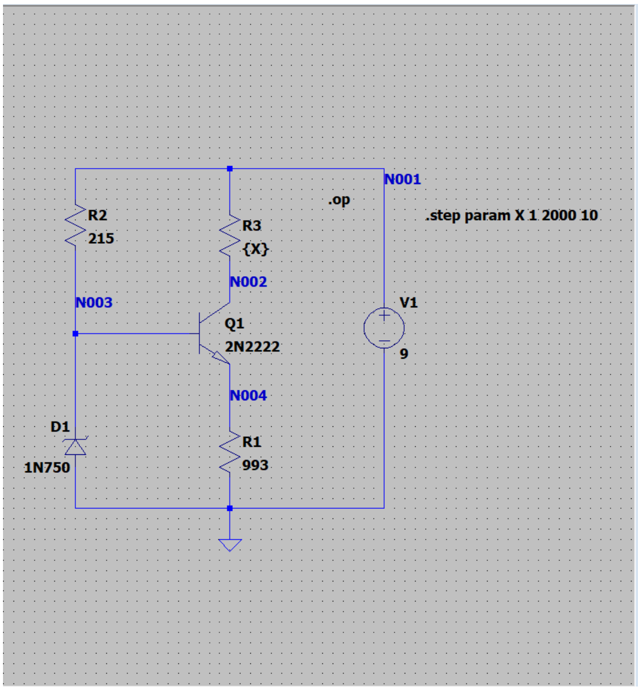
$V_{BE} = 0.7V$

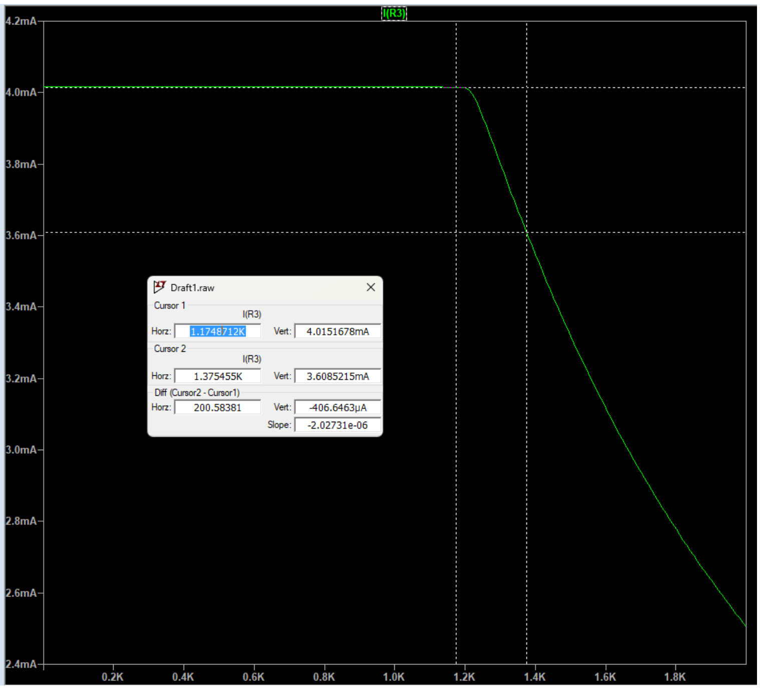
2. R1 = 215Ω, R2 = 993Ω



3. To have a constant current V_{CE} has to be higher than 0.3V (from 2N2222 datasheet) to stay in active mode. So the condition for RL is $V_{RL} < V_{CC} - 0.3V - V_2 = V_{RL} < 4.7V$ so R_L must be lower than $\frac{4.7}{0.004} = 1175\ \Omega$.

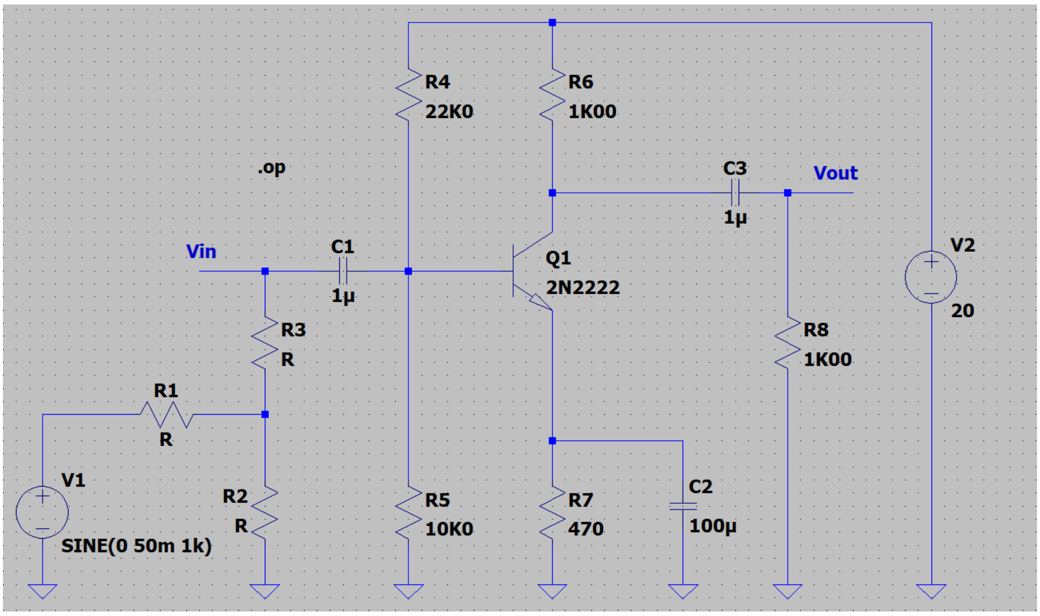
4. **Max R_L in LTSpice**





At 1275Ω the current is 4mA, at 1375Ω the current is 10% less (3.6mA).

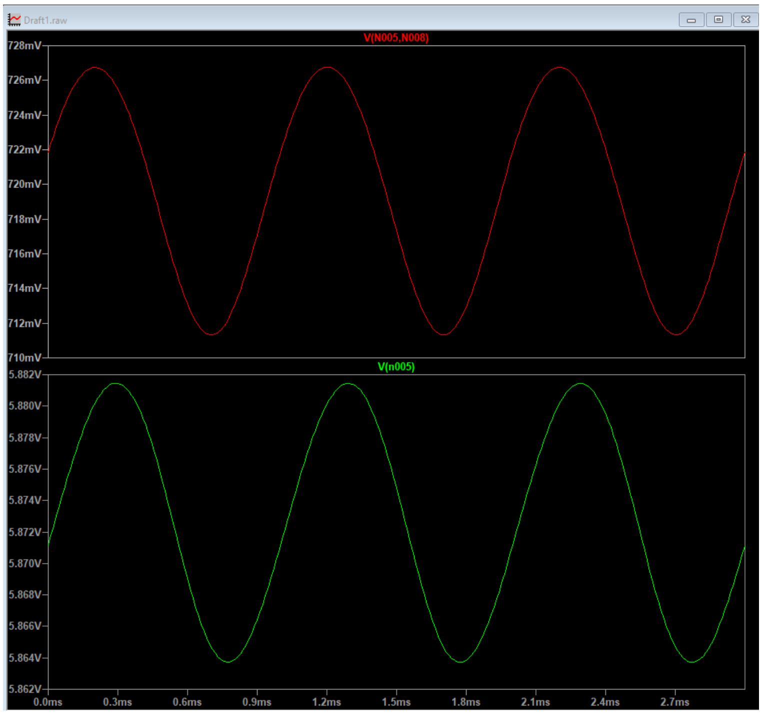
3.3 Amplifier circuit

1. 

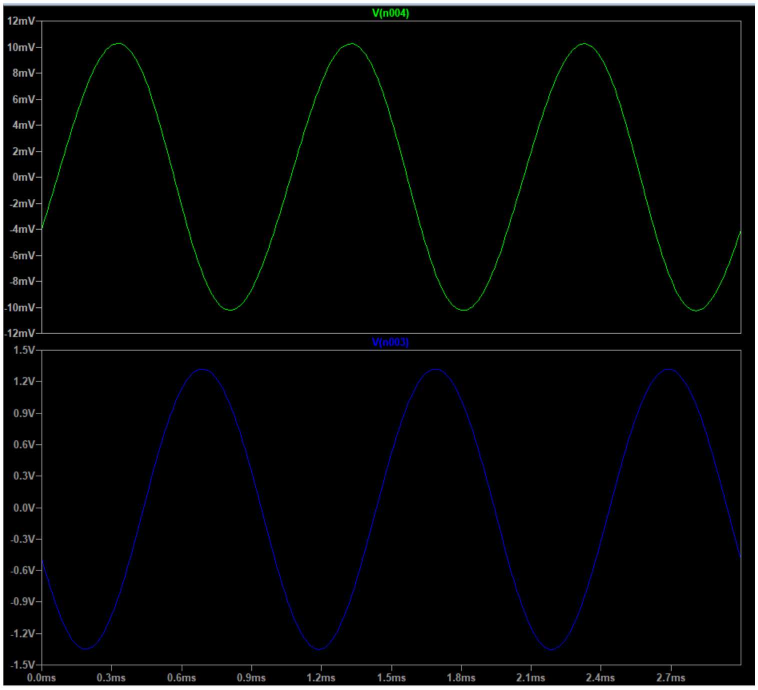
2. **DC operation point values**

$I_C = 0.011$ A, $I_B = 54.7$ uA
$V_B = 5.87$V, $V_E = 5.15$ V, $V_C = 9.09$V, $V_BE = 0.12$, $V_CE = 3.94$V

3. **Transient analysis at 50mV**



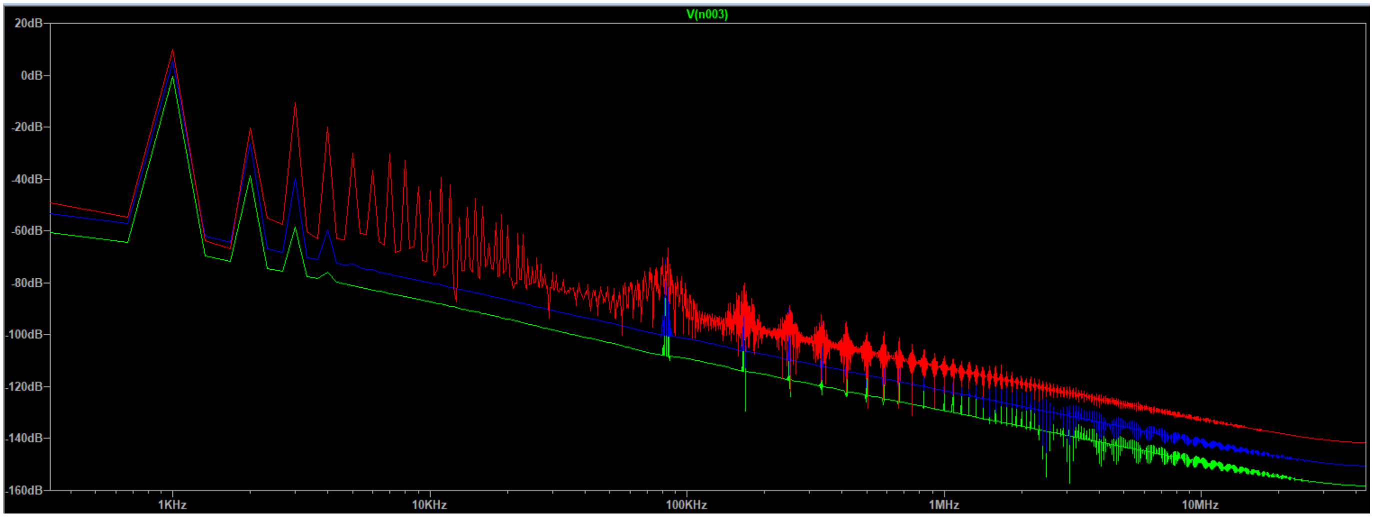
Green line: V_B: 17.7mV peak to peak, red line: V_{BE}: 15.4mV peak to peak.



Green line: V_i: 20.5mV peak to peak, blue line: V_o: 2.67V.

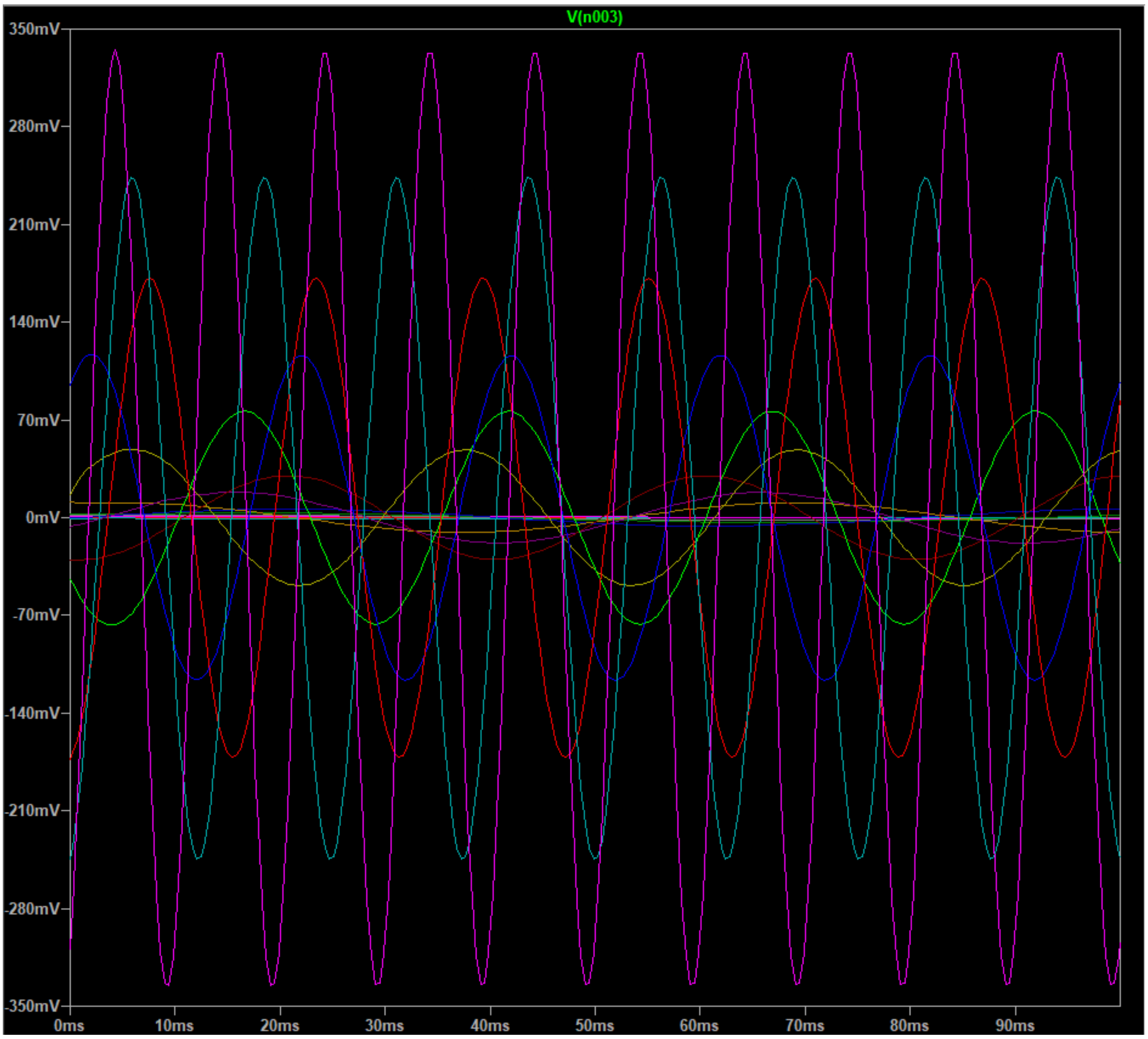
Gain: $\frac{V_o}{V_i} = 130$.

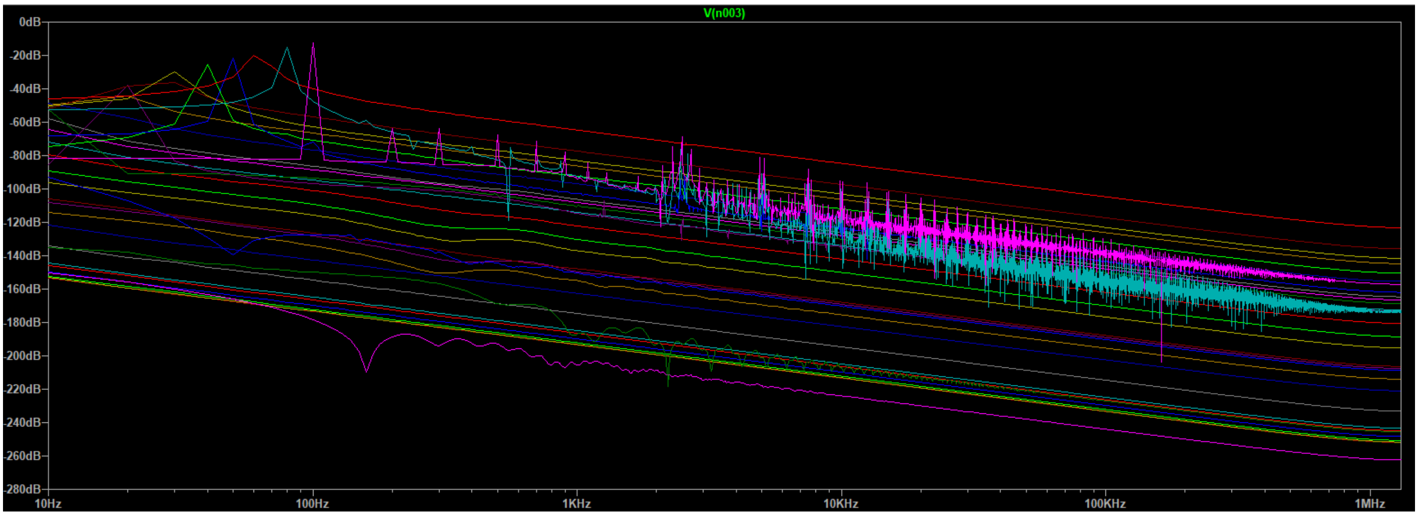
4. **Harmonic distortion analysis**



According to the FFT the harmonic distortion is similar between 50mV and 100mV as input amplitude and is much worse when using 200mV.

5. **AC analysis**





6. **Bandwidth measurement**

Lower -3dB frequency: 326.2 Hz
Upper -3dB frequency: 479.5 kHz
Bandwidth: 479.3 kHz