K. J. SOMAIYA COLLEGE OF ENGINEERING
DEPARTMENT OF ELECTRONICS ENGINEERING
ELECTRONIC CIRCUITS
Multi-transistor Circuits

**Numerical 1:**

Calculate the voltage gain of each stage and the overall AC voltage gain for the BJT cascade amplifier circuit shown in figure 1. Given $\beta_1 = 150$ & $\beta_2 = 150$

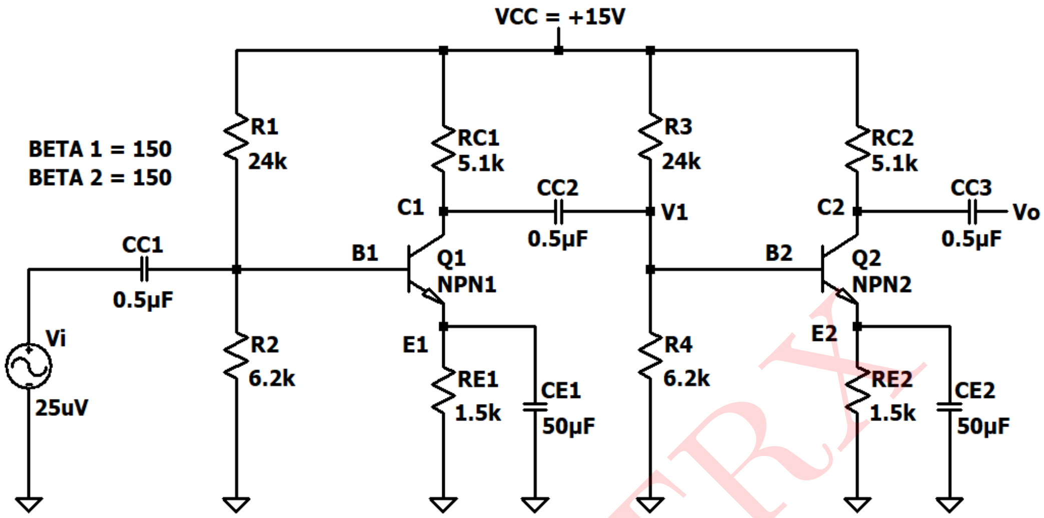


Figure 1: Circuit 1

**Solution:**

**DC Analysis:**

Due to R-C coupling, both the stages Q point are isolated.

Since both stages are symmetric in parameters & resistor values, DC analysis of one stage is sufficient

For DC analysis all the capacitors are open circuited, since f = $0Hz$

Hence the circuit becomes,

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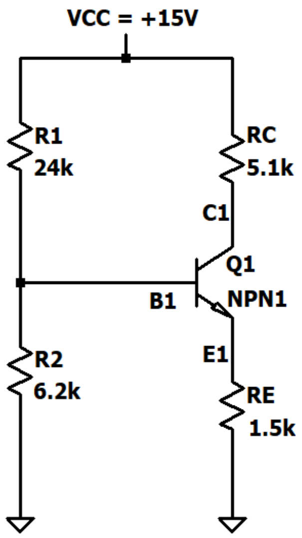


Figure 2: DC Equivalent Circuit

Applying Thevenin's theorem at the base of the transistor,

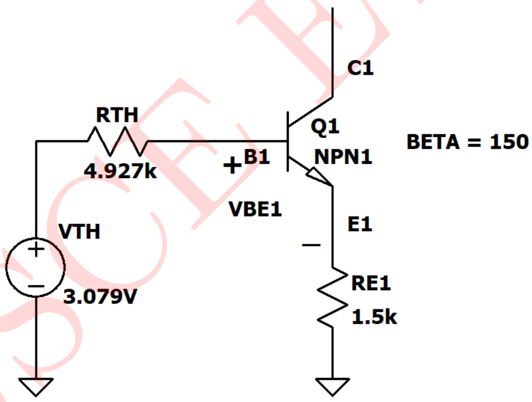


Figure 3: Thevenin's Equivalent Circuit

$$V_{TH} = \frac{R_2 \times V_{CC}}{R_1 + R_2} = \frac{6.2k\Omega \times 15V}{24k\Omega + 6.2k\Omega} = \mathbf{3.079V}$$

$$R_{TH} = R_1 \parallel R_2 = 24k\Omega \parallel 6.2k\Omega = \mathbf{4.927k\Omega}$$

Applying KVL to input Base Emitter loop,

$V_{TH} - I_{B_1Q}R_{TH} - V_{BE_1} - I_{E_1Q}R_{E_1} = 0$

$V_{TH} - I_{B_1Q}R_{TH} - V_{BE_1} - (1+\beta_1)I_{B_1Q}R_{E_1} = 0$ [Since, $I_E = (1+\beta)I_B$]

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$$I_{B_1Q} = \frac{V_{TH} - V_{BE_1}}{R_{TH} + (1+\beta_1)R_{E_1}}$$
$$= \frac{3.079 - 0.7}{4.927k\Omega + (151) \times 1.5k\Omega}$$
$$= \mathbf{10.279\mu A}$$

$$I_{C_1Q} = \beta_1 I_{B_1Q} = 150 \times 10.279\mu A = \mathbf{1.54mA}$$

Applying KVL to output Collector Emitter loop,

$$V_{CC} - I_{C_1Q}R_{C_1} - V_{CE_1Q} - I_{C_1Q}R_{E_1} = 0$$

$$V_{CE_1Q} = V_{CC} - I_{C_1Q}(R_{C_1} + R_{E_1})$$
$$= 15V - (1.54mA)(5.1k\Omega + 1.5k\Omega)$$
$$= 15V - 10.225V$$
$$= \mathbf{4.775V}$$

**Small Signal Parameters:**

$r_{o_1} = r_{o_2} = \infty$ [Assumption]

$$r_{\pi_1} = \frac{\beta_1 V_T}{I_{C_1Q}}$$
$$= \frac{150 \times 0.026V}{1.54mA}$$
$$= \mathbf{2.532k\Omega}$$

$$g_{m_1} = \frac{I_{C_1Q}}{V_T}$$
$$= \frac{1.54mA}{26mV}$$
$$= \mathbf{59.23mA/V}$$

Since both stages are identical,

$r_{\pi_1} = r_{\pi_2} = \mathbf{2.532k\Omega}$ & $g_{m_1} = g_{m_2} = \mathbf{59.23mA/V}$

**Mid Band AC Equivalent Circuit:**

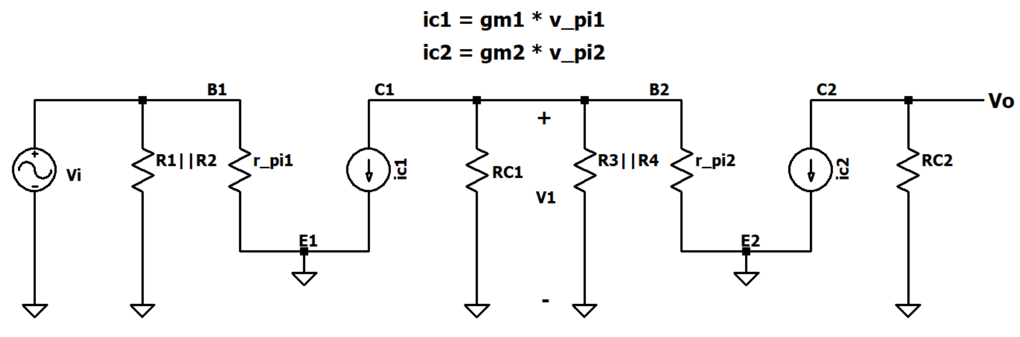


Figure 4: Small Signal Equivalent Circuit

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Voltage gain of first stage: $Av_1 = \frac{V_1}{V_i}$

$$Av_1 = \frac{V_1}{V_i} = \frac{-g_{m_1} V_{\pi_1} (R_{C_1} \parallel R_3 \parallel R_4 \parallel r_{\pi_2})}{V_{\pi_1}}$$

$$\begin{aligned} Av_1 &= -g_{m_1} (R_{C_1} \parallel R_3 \parallel R_4 \parallel r_{\pi_2}) \\ &= -(59.23mA/V)(5.1k\Omega \parallel 24k\Omega \parallel 6.2k\Omega \parallel 2.532k\Omega) \\ &= -(59.23mA/V)(1259.477\Omega) \\ &= \mathbf{-74.59} \end{aligned}$$

Voltage gain of second stage: $Av_2 = \frac{V_o}{V_1}$

$$Av_2 = \frac{V_o}{V_1} = \frac{-g_{m_2} V_{\pi_2} (R_{C_2})}{V_{\pi_2}}$$

$$\begin{aligned} Av_2 &= -g_{m_2} (R_{C_2}) \\ &= -(59.23mA/V)(5.1k\Omega) \\ &= \mathbf{-302} \end{aligned}$$

**Input Impedance of first stage ($\mathbf{Z_i}$):**

$$\begin{aligned} Z_i &= R_1 \parallel R_2 \parallel r_{\pi_1} \\ &= 24k\Omega \parallel 6.2k\Omega \parallel 2.532\Omega \\ &= \mathbf{1.672k\Omega} \end{aligned}$$

**Output Impedance of second stage ($\mathbf{Z_o}$):**

$$\begin{aligned} Z_o &= R_{C_2} \\ &= \mathbf{5.1k\Omega} \end{aligned}$$

**Overall Voltage Gain:** $A_{V_T} = \frac{V_o}{V_i}$

$$A_{V_T} = \frac{V_o}{V_i} = \frac{V_1}{V_i} \times \frac{V_o}{V_1}$$

$$\begin{aligned} \therefore A_{V_T} &= A_{V_1} \times A_{V_2} \\ &= (-74.59) \times (-302) \\ &= \mathbf{22526.18} \end{aligned}$$

$$\begin{aligned} |A_{V_T}| \text{ in dB} &= 20 \log_{10} (A_{V_T}) \\ &= 20 \log_{10} (22526.18) \\ &= \mathbf{87.05}\text{dB} \end{aligned}$$

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**Output Voltage ($\mathbf{V_o}$):**

$$A_{V_T} = \frac{V_o}{V_i} \implies V_o = A_{V_T} \times V_i$$

$$V_i = 25\mu V \quad \text{[peak to peak]}$$

$$\begin{aligned} \therefore V_o &= A_{V_T} \times V_i \\ &= 22526.18 \times 25\mu V \\ &= \mathbf{0.563V} \end{aligned}$$

## SIMULATED RESULTS

The above circuit is simulated in LTspice and results are presented below:

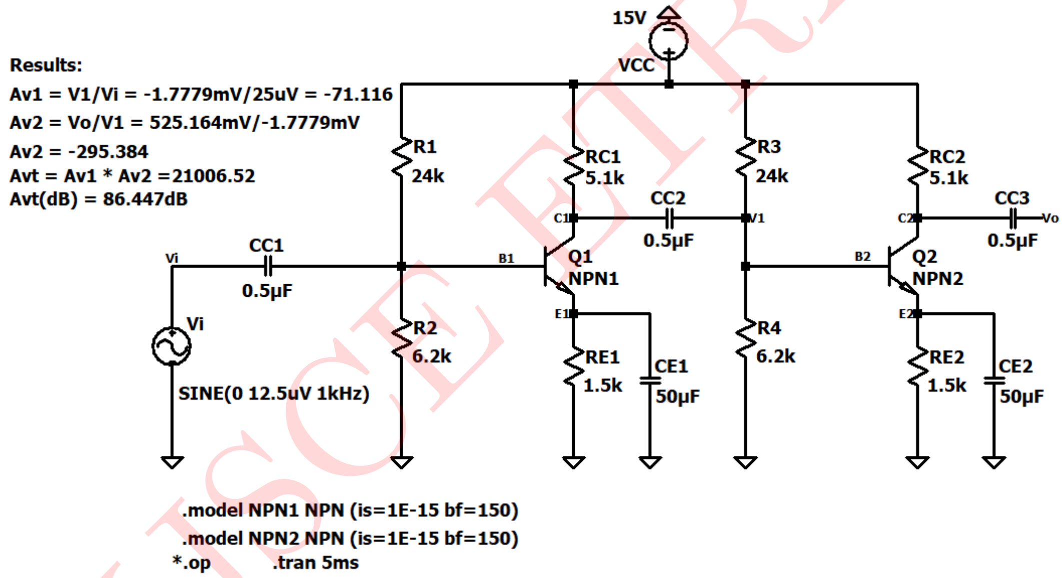


Figure 5: Circuit Schematic

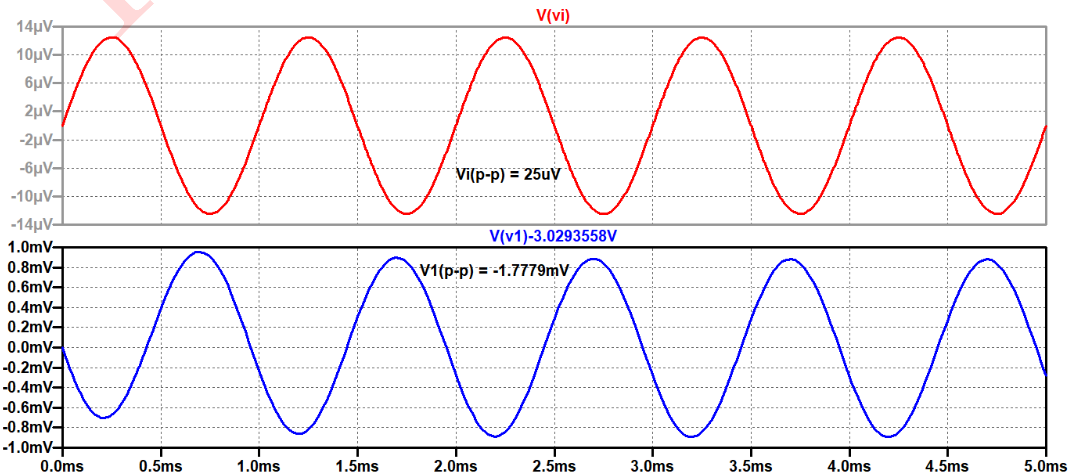


Figure 6: Input Output waveforms of 1st stage

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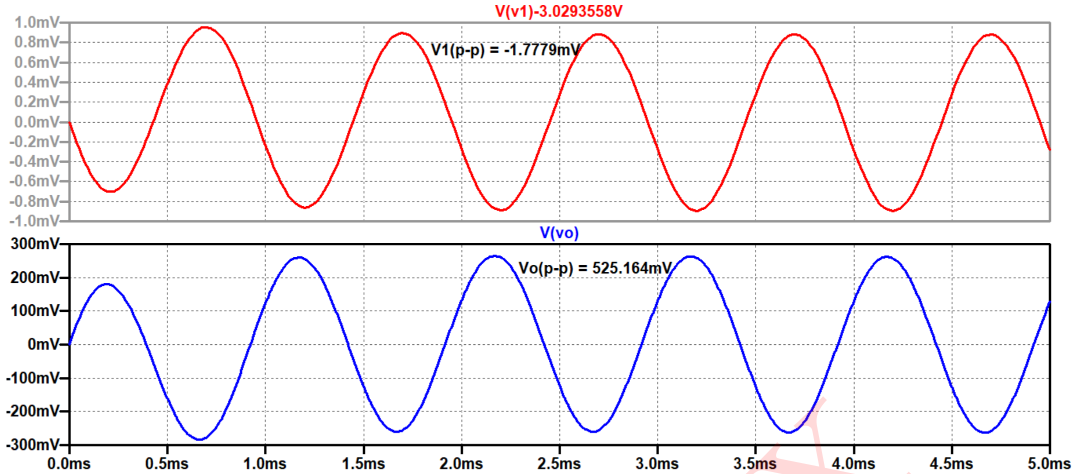


Figure 7: Input Output waveforms of 2nd stage

**Comparison of Theoretical and Simulated results:**

| Parameters | Theoretical | Simulated |
|---|---|---|
| Q point: $I_{C_1Q}, V_{CE_1Q}$ | $1.54mA, 4.775V$ | $1.525mA, 4.916V$ |
| Q point: $I_{C_2Q}, V_{CE_2Q}$ | $1.54mA, 4.775V$ | $1.525mA, 4.916V$ |
| Voltage gain of 1st stage: $Av_1$ | $-74.59$ | $-71.116$ |
| Voltage gain of 2nd stage: $Av_2$ | $-302$ | $-295.384$ |
| Overall Voltage gain: $A_{V_T}$ | 22526.18 | 21006.52 |
| Input Impedance of 1st stage: $Z_i$ | $1.672k\Omega$ | $-$ |
| Output Impedance of 2nd stage: $Z_o$ | $5.1k\Omega$ | $-$ |
| Output Voltage | $0.563V$ | $0.525V$ |
| Overall voltage gain $A_{V_T}$ in dB | 87.05dB | 86.447dB |

Table 1: Numerical 1

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### Numerical 2:

For the JFET cascade amplifier given in figure 8, using identical JFET's with $I_{DSS} = 8mA$ & $V_p = -4.5V$, calculate the voltage gain of each stage, the overall gain of the amplifer & the output voltage $V_o$.

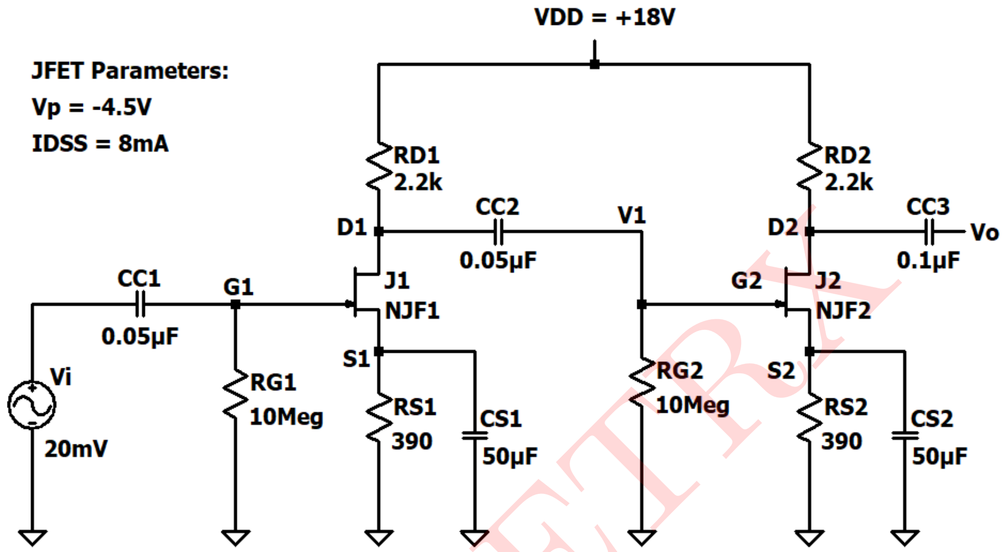


Figure 8: Circuit 2

**Solution:** Since both stages of given amplifier are symmetric, DC analysis of single stage is sufficient

### DC Analysis:

For DC analysis all the capacitors will get open circuited as f = $0Hz$

Thus the circuit becomes,

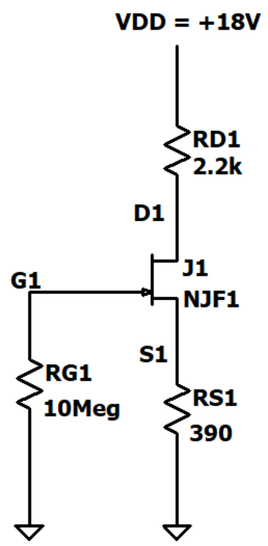


Figure 9: DC Equivalent Circuit

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$$
\begin{aligned}
V_{GS_1} &= V_{G_1} - V_{S_1} \\
&= 0 - I_{D_1} R_{S_1} && [\because I_G = 0] \\
&= -I_{D_1}(390) \\
&= -390 I_{D_1} && .....(1)
\end{aligned}
$$

$$
\begin{aligned}
I_{D_1} &= I_{DSS} \left(1 - \frac{V_{GS_1}}{V_p}\right)^2 \\
&= (8mA)\left(1 + \frac{V_{GS_1}}{4.5}\right)^2 && .....(2)
\end{aligned}
$$

Substituting equation (2) in equation (1),

$$
\begin{aligned}
V_{GS_1} &= -3.12 \left(1 + \frac{V_{GS_1}}{4.5}\right)^2 \\
&= -3.12 \left(1 + 0.44 V_{GS_1} + 0.0493 V_{GS_1}^2\right) \\
&= -3.12 - 1.3728 V_{GS_1} - 0.1538 V_{GS_1}^2
\end{aligned}
$$

$$0.1538 V_{GS_1}^2 + 2.3728 V_{GS_1} + 3.12 = 0$$

$$V_{GS_1} = -1.45V \quad \text{or} \quad V_{GS_1} = -13.976V$$

$\because V_{GS} > V_p, \therefore V_{GSQ_1} = -\mathbf{1.45V}$

$$
\begin{aligned}
I_{DQ_1} &= I_{DSS} \left(1 - \frac{V_{GSQ_1}}{V_p}\right)^2 \\
&= (8mA)\left(1 - \frac{(-1.45V)}{-4.5V}\right)^2 \\
&= \mathbf{3.675mA}
\end{aligned}
$$

Since both stages are identical

$\therefore V_{GSQ_1} = V_{GSQ_2} \quad \& \quad I_{DQ_1} = I_{DQ_2}$

**Small Signal Parameter:**

$$
\begin{aligned}
g_{m_1} &= \frac{2 I_{DSS}}{|V_p|} \left(1 - \frac{V_{GSQ_1}}{V_p}\right) \\
&= \frac{2 \times 8mA}{4.5} \left(1 - \frac{(-1.45V)}{-4.5V}\right) \\
&= \mathbf{2.4mA/V}
\end{aligned}
$$

$\because$ Both stages are identical,

$\therefore g_{m_1} = g_{m_2}$

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**Mid frequency AC Equivalent Circuit:**

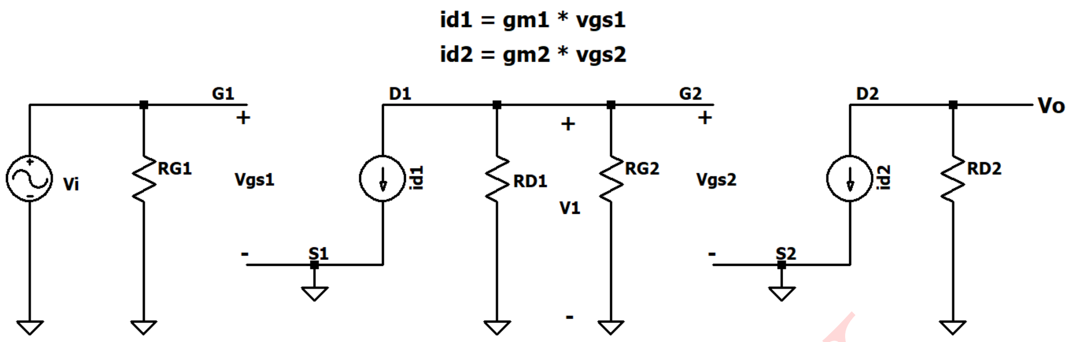


Figure 10: Small Signal Equivalent Circuit

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Gain of $1^{st}$ stage: $Av_1 = \dfrac{V_1}{V_i}$

$$Av_1 = \frac{V_1}{V_i} = \frac{(-g_{m_1}V_{gs_1})(R_{D_1} \parallel R_{G_2})}{V_{gs_1}}$$

$$\begin{aligned} Av_1 &= -g_{m_1}(R_{D_1} \parallel R_{G_2}) \\ &= -(2.4mA/V)(2.2k\Omega \parallel 10M\Omega) \\ &= -(2.4mA/V)(2.199k\Omega) \\ &= -\mathbf{5.28} \end{aligned}$$

Gain of $2^{nd}$ stage: $Av_2 = \dfrac{V_o}{V_1}$

$$\begin{aligned} Av_2 &= \frac{(-g_{m_2}V_{gs_2})(R_{D_2})}{V_{gs_2}} \\ &= -g_{m_2}R_{D_2} \\ &= -(2.4mA/V)(2.2k\Omega) \\ &= -\mathbf{5.28} \end{aligned}$$

**Overall Voltage Gain:** $A_{V_T} = \dfrac{V_o}{V_i}$

$$A_{V_T} = \frac{V_1}{V_i} \times \frac{V_o}{V_1}$$

$$\begin{aligned} \therefore A_{V_T} &= A_{V_1} \times A_{V_2} \\ &= (-5.28) \times (-5.28) \\ &= \mathbf{27.8784} \end{aligned}$$

$$\begin{aligned} |A_{V_T}| \text{ in dB} &= 20\log_{10}(A_{V_T}) \\ &= \mathbf{28.9}\text{dB} \end{aligned}$$

**Input Impedance of $1^{st}$ stage ($\mathbf{Z_i}$):**

$Z_i = R_{G_1} = 10M\Omega$

$\therefore Z_i = \mathbf{10M\Omega}$

**Output Impedance of $2^{nd}$ stage ($\mathbf{Z_o}$):**

$Z_o = R_{o_2}$

$\therefore Z_o = 2.2k\Omega$

**Output Voltage ($\mathbf{V_o}$):**

$$A_{V_T} = \frac{V_o}{V_i} \implies V_o = A_{V_T} \times V_i$$

$\therefore V_o = 27.8784 \times (20mV) = \mathbf{0.5575V}$

## SIMULATED RESULTS

The above circuit is simulated in LTspice and results are presented below:

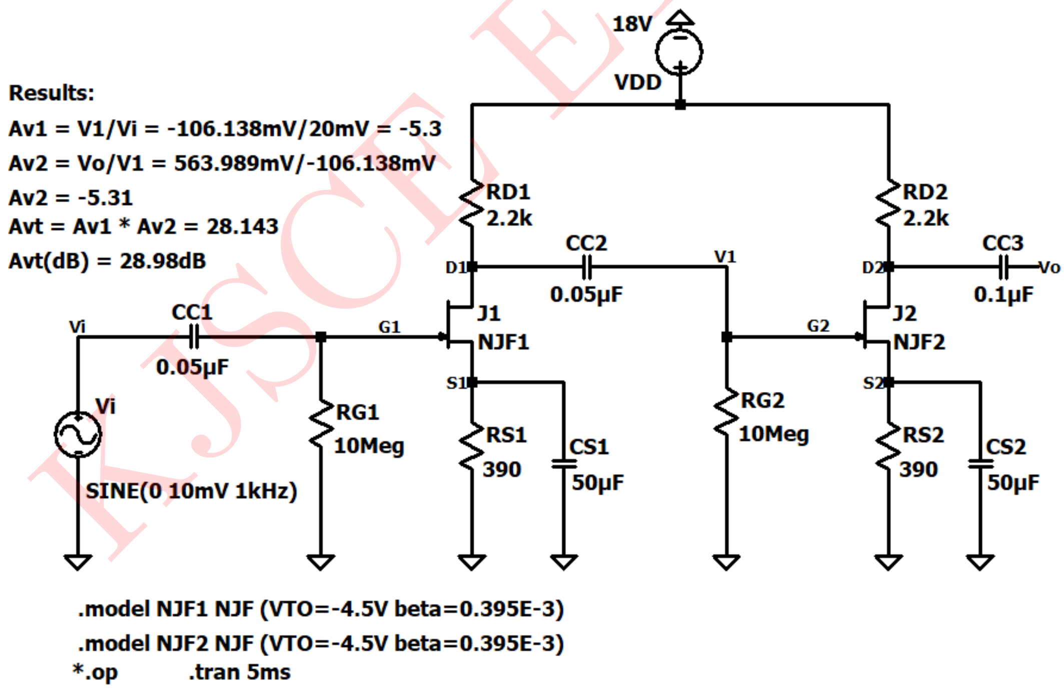


Figure 11: Circuit Schematic

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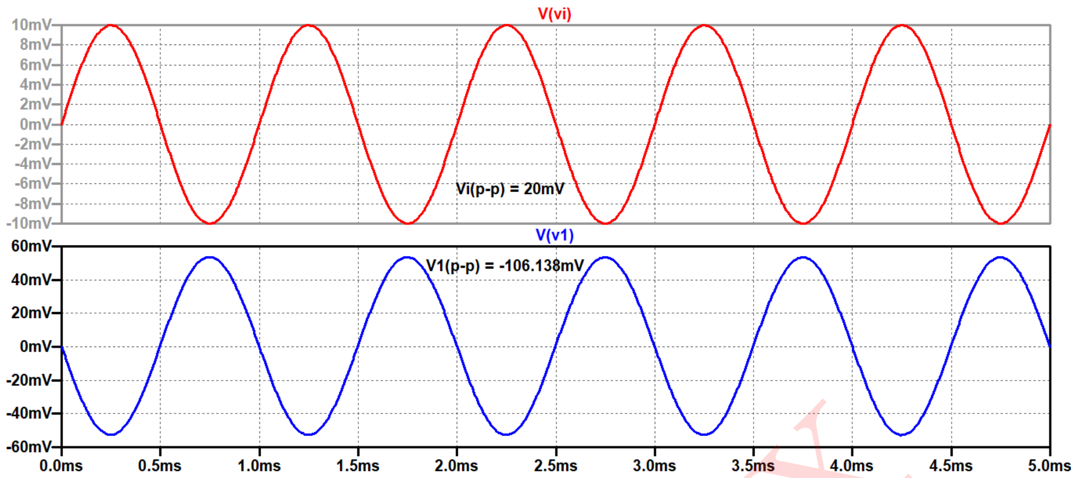


Figure 12: Input Output waveforms of 1st stage

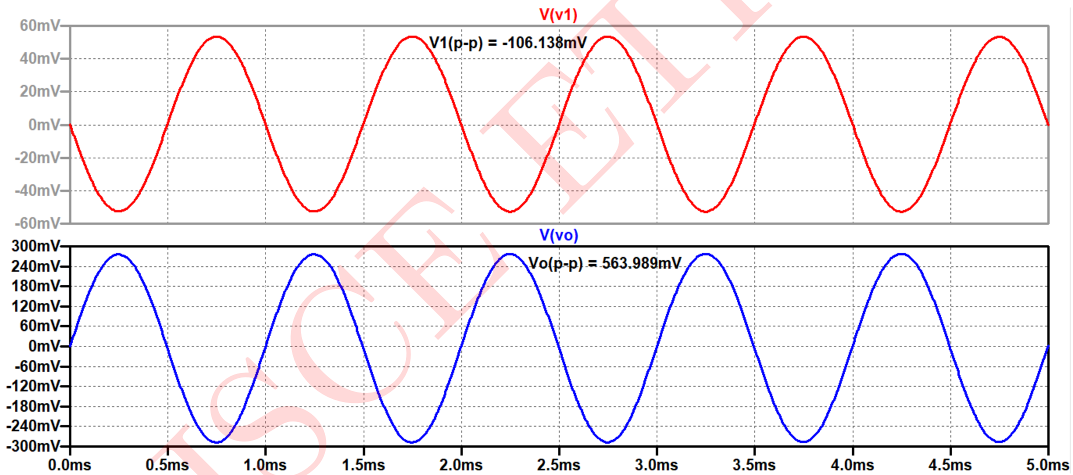


Figure 13: Input Output waveforms of 2nd stage

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**Comparison of Theoretical and Simulated results:**

| Parameters | Theoretical | Simulated |
|---|---|---|
| Q point: $I_{DQ_1}, V_{GSQ_1}$ | $3.675mA, -1.45V$ | $3.69mA, -1.44V$ |
| Q point: $I_{DQ_2}, V_{GSQ_2}$ | $3.675mA, -1.45V$ | $3.69mA, -1.44V$ |
| Voltage gain of 1st stage: $Av_1$ | $-5.28$ | $-5.3$ |
| Voltage gain of 2nd stage: $Av_2$ | $-5.28$ | $-5.31$ |
| Overall Voltage gain: $A_{V_T}$ in dB | $28.9dB$ | $28.98dB$ |
| Input Impedance of 1st stage: $Z_i$ | $10M\Omega$ | $-$ |
| Output Impedance of 2nd stage: $Z_o$ | $2.2k\Omega$ | $-$ |
| Output Voltage: $V_o$ | $0.5575V$ | $0.5639V$ |

Table 2: Numerical 2

**Numerical 3:**

Determine the small signal voltage gain of the multitransistor circuit shown in figure 14. Given $\beta_1 = 150$ & $\beta_2 = 200$

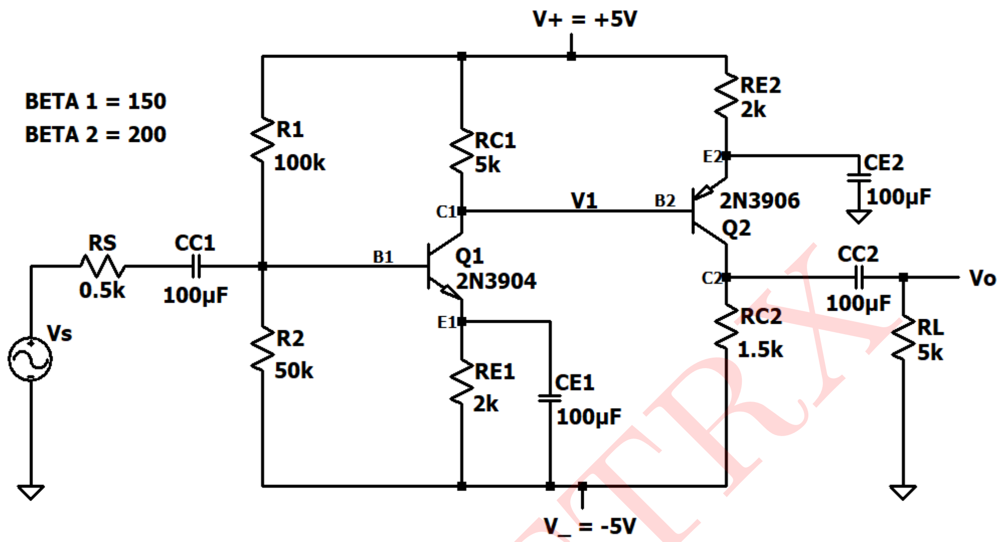


Figure 14: Circuit 3

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**Solution:**

From datasheet,

For 2N3904, $\beta_1 = 150$, $V_{BE} = 0.7V$ & For 2N3906, $\beta_2 = 200$, $V_{EB} = 0.7V$

**DC Analysis:**

For DC analysis we will short circuit all the capacitors, since frequency is $0Hz$

Thus the circuit becomes,

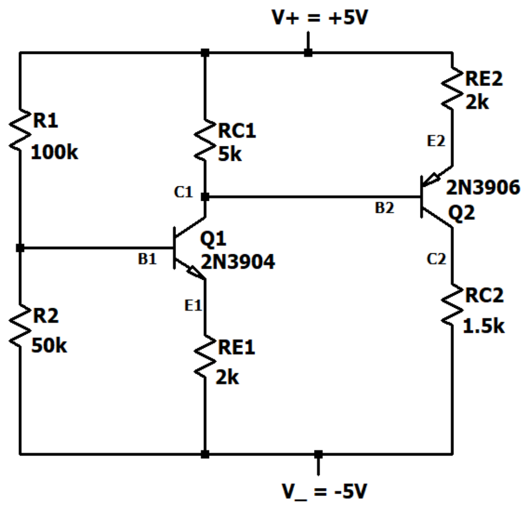


Figure 15: DC Equivalent Circuit

Considering the Thevenin's Equivalent of base circuit of transistor $Q_1$

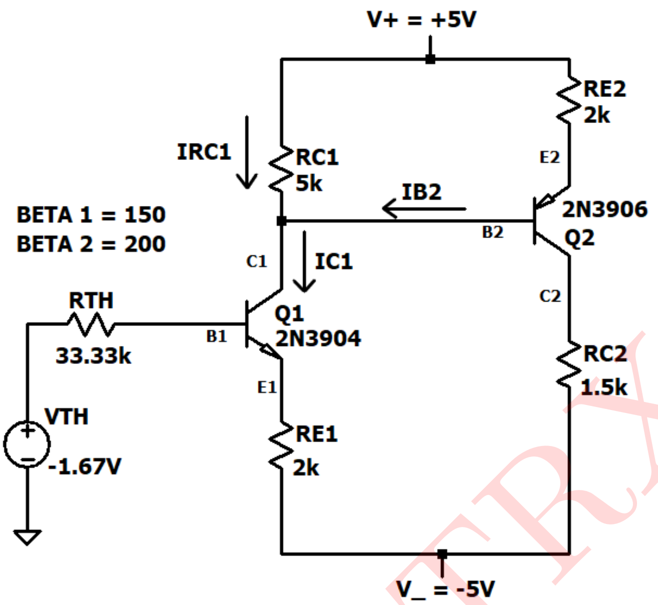


Figure 16: DC Equivalent Circuit with Thevenin's Equivalent Circuit

$$\begin{aligned} V_{TH} &= \frac{R_2}{R_1 + R_2}(V_+ - V_-) - V_- \\ &= \frac{50k\Omega}{100k\Omega + 50k\Omega} \times (10V - 5V) \\ &= \mathbf{-1.67V} \end{aligned}$$

$$\begin{aligned} R_{TH} &= R_1 \parallel R_2 \\ &= 100k\Omega \parallel 50k\Omega \\ &= \mathbf{33.33k\Omega} \end{aligned}$$

Applying KVL to Base Emitter loop of $Q_1$,

$V_{TH} - I_{B_1}R_{TH} - V_{BE_1} - I_{E_1}R_{E_1} = V_-$

$V_{TH} - I_{B_1}R_{TH} - V_{BE_1} - (1+\beta_1)I_{B_1}R_{E_1} - V_- = 0$ [Since, $I_E = (1+\beta)I_B$]

$$\begin{aligned} I_{B_1} &= \frac{V_{TH} - V_{BE_1} - V_-}{R_{TH} + (1+\beta_1)R_{E_1}} \\ &= \frac{-1.67 - 0.7 + 5}{33.33k\Omega + (151) \times 2k\Omega} \\ &= \mathbf{7.84\mu A} \end{aligned}$$

$$I_{C_1} = \beta_1 I_{B_1} = 150 \times 7.84\mu A = \mathbf{1.176mA}$$

$$I_{E_1} = I_{C_1} + I_{B_1} = 1.176 + 7.84 = \mathbf{1.183mA}$$

$$\begin{aligned} V_{C_1} &= V_{CC} - I_{C_1}R_{C_1} \\ &= 5 - (1.176mA \times 5k\Omega) \\ &= \mathbf{-0.88V} \end{aligned}$$ [Ignoring $I_{B_2}$ & $I_{RC_1} \cong I_{C_1}$]

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$$\begin{aligned}
V_{E_2} &= V_{B_2} + V_{EB_2} \\
&= V_{C_1} + V_{EB_2} && [\because V_{C_1} = I_{B_2}] \\
&= -0.88 + 0.7 \\
&= \mathbf{-0.18V}
\end{aligned}$$

$$\begin{aligned}
I_{E_2} &= \frac{V_+ - V_{E_2}}{R_{E_2}} \\
&= \frac{5 - (-0.18)}{2k\Omega} \\
&= \mathbf{2.59mA}
\end{aligned}$$

$$\begin{aligned}
I_{C_2} &= \frac{\beta_2}{1+\beta_2} I_{E_2} \\
&= \frac{200}{1+200} \times 2.59mA \\
&= \mathbf{2.577mA}
\end{aligned}$$

$$\begin{aligned}
I_{B_2} &= \frac{I_{E_2}}{1+\beta_2} \\
&= \frac{2.59}{1+200} \\
&= \mathbf{12.88\mu A}
\end{aligned}$$

Now, rewriting the exact expression for equation (1),

$$V_{C_1} = V_{CC} - I_{RC_1} R_{C_1}$$

$$I_{RC_1} = I_{C_1} - I_{B_2} = 1.176mA - 12.88\mu A = \mathbf{1.163mA}$$

$$\begin{aligned}
V_{C_1} &= V_+ - I_{RC_1} R_{C_1} \\
&= 5 - (1.163mA \times 5k\Omega) \\
&= \mathbf{-0.815V}
\end{aligned}$$

$$\begin{aligned}
V_{E_2} &= V_{B_2} + V_{EB_2} \\
&= V_{C_1} + V_{EB_2} && [\because V_{C_1} = V_{B_2}] \\
&= -0.815 + 0.7 \\
&= \mathbf{-0.115V}
\end{aligned}$$

$$\begin{aligned}
I_{E_2} &= \frac{V_+ - V_{E_2}}{R_{C_2}} \\
&= \frac{5 - (-0.115)}{2k\Omega} \\
&= \mathbf{2.5575mA}
\end{aligned}$$

$$\begin{aligned}
I_{C_2} &= \frac{\beta_2}{1+\beta_2} I_{E_2} \\
&= \frac{200}{1+200} \times 2.5575mA = \mathbf{2.544mA}
\end{aligned}$$

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$$
\begin{aligned}
I_{B_2} &= \frac{I_{E_2}}{1+\beta_2} \\
&= \frac{2.5575}{1+200} \\
&= \mathbf{12.72\mu A}
\end{aligned}
$$

$$
\begin{aligned}
V_{E_1} &= I_{E_1}R_{E_1} + V_- \\
&= (1.183mA \times 2k\Omega) - 5 \\
&= \mathbf{-2.634V}
\end{aligned}
$$

$$
\begin{aligned}
V_{CE_1} &= I_{C_1} - V_{E_1} \\
&= -0.815 - (-2.634) \\
&= \mathbf{1.819V}
\end{aligned}
$$

$$
\begin{aligned}
V_{C_2} &= I_{C_2}R_{C_2} - V_- \\
&= (2.544mA \times 1.5k\Omega) - 5 \\
&= \mathbf{-1.184V}
\end{aligned}
$$

$$
\begin{aligned}
V_{EC_2} &= V_{E_2} - V_{C_2} \\
&= -0.115 - (-1.184) \\
&= \mathbf{1.069V}
\end{aligned}
$$

**Node Voltages:**

$V_{B_1} = -1.934V$, $V_{C_1} = -0.815V$, $V_{E_1} = -2.634V$

$V_{C_2} = -1.184V$, $V_{E_1} = -0.115V$, $V_{B_1} = -0.815V$

**Terminal Currents:**

$I_{B_1} = 7.84\mu A$, $I_{C_1} = 1.176mA$, $I_{E_1} = 1.183mA$

$I_{B_2} = 12.72\mu A$, $I_{C_2} = 2.544mA$, $I_{E_2} = 2.5575mA$

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**AC Equivalent Circuit:**

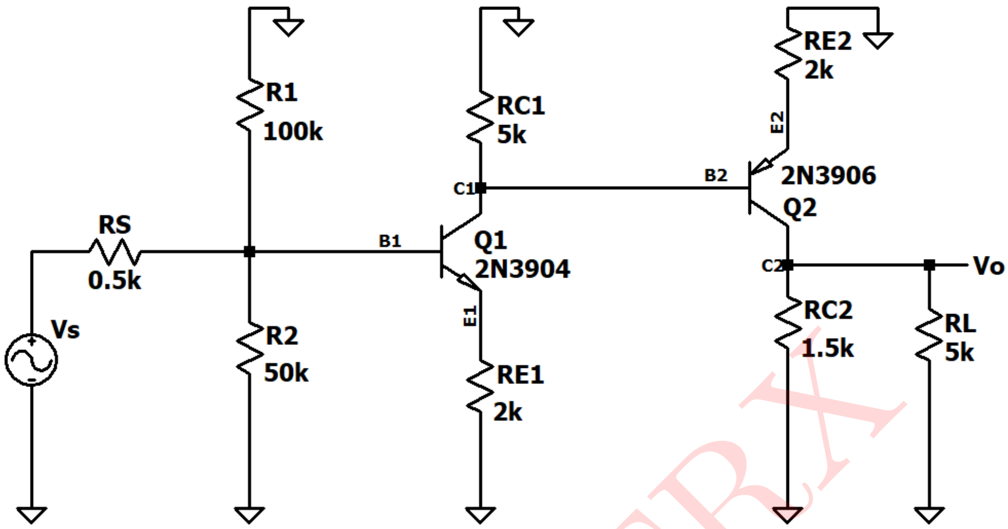


Figure 17: AC Equivalent Circuit

**Small Signal Parameters:**

$$
\begin{aligned}
g_{m_1} &= \frac{I_{C_1}}{V_T} \\
&= \frac{1.176mA}{26mV} \\
&= \mathbf{45.23mA/V}
\end{aligned}
$$

$$
\begin{aligned}
r_{\pi_1} &= \frac{\beta_1 V_T}{I_{C_1}} \\
&= \frac{150 \times 26mV}{1.176mA} \\
&= \mathbf{3.316k\Omega}
\end{aligned}
$$

$$
\begin{aligned}
g_{m_2} &= \frac{I_{C_2}}{V_T} \\
&= \frac{2.544mA}{26mV} \\
&= \mathbf{97.846mA/V}
\end{aligned}
$$

$$
\begin{aligned}
r_{\pi_2} &= \frac{\beta_2 V_T}{I_{C_2}} \\
&= \frac{200 \times 0.026V}{2.544mA} \\
&= \mathbf{2.044k\Omega}
\end{aligned}
$$

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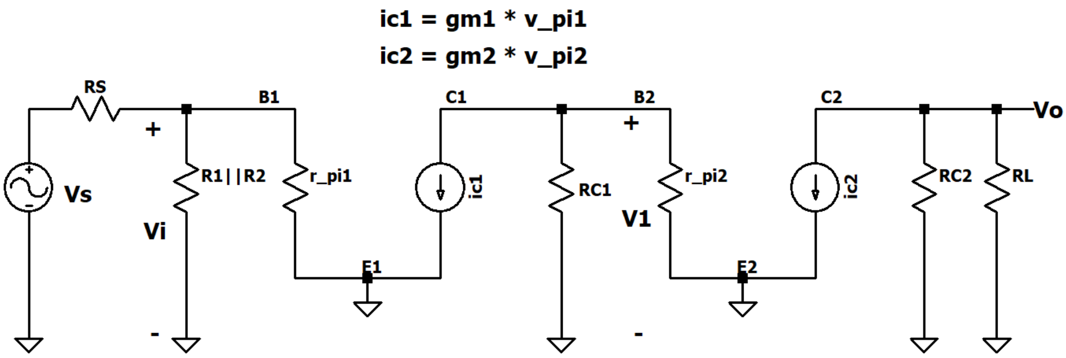


Figure 18: Small Signal Equivalent Circuit

$$A_{V_T} = \frac{V_o}{V_s} = \frac{V_o}{V_1} \times \frac{V_1}{V_s}$$

$$Av_1 = \frac{V_1}{V_s} = \frac{V_1}{V_i} \times \frac{V_i}{V_s}$$

$$V_i = \frac{R_1 \parallel R_2}{R_1 \parallel R_2 + R_S} V_s$$

$$\frac{V_i}{V_s} = \frac{R_1 \parallel R_2}{R_1 \parallel R_2 + R_S}$$

$$\begin{aligned} Av_1 &= \frac{-g_{m_1} V_{\pi_1}(R_{C_1} \parallel r_{\pi_2})}{V_{\pi_1}} \times \frac{R_1 \parallel R_2}{R_1 \parallel R_2 + R_S} \\ &= -g_{m_1}(R_{C_1} \parallel r_{\pi_2}) \times \frac{R_1 \parallel R_2}{R_1 \parallel R_2 + R_S} \\ &= -(45.23mA/V) \times (5k\Omega \parallel 2.044k\Omega) \times \frac{33.33k\Omega}{33.33k\Omega + 0.5k\Omega} \\ &= -(45.23mA/V) \times (1.45k\Omega) \times (0.985) \\ &= \mathbf{-64.599} \end{aligned}$$

$$\begin{aligned} Av_2 &= \frac{V_o}{V_1} = \frac{-g_{m_2} V_{\pi_2}(R_{C_2} \parallel R_L)}{V_{\pi_2}} \\ &= -g_{m_2}(R_{C_2} \parallel R_L) \\ &= -(97.846mA/V) \times (1.5k\Omega \parallel 5k\Omega) \\ &= -(97.846mA/V) \times (1.153k\Omega) \\ &= \mathbf{-112.816} \end{aligned}$$

**Overall Volatge Gain ($\mathbf{A_{V_T}}$):**

$$\begin{aligned} A_{V_T} &= Av_1 \times Av_2 \\ &= (-64.599) \times (-112.816) \\ &= \mathbf{7287.8} \end{aligned}$$

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$$
\begin{aligned}
A_{V_T} \text{ in dB} &= 20\log_{10}\left(A_{V_T}\right) \\
&= 20\log_{10}(7287.8) \\
&= \mathbf{77.251}\text{dB}
\end{aligned}
$$

**Output Voltage ($\mathbf{V_o}$):**

$$A_{V_T} = \frac{V_o}{V_i} \quad \Longrightarrow \quad V_o = A_{V_T} \times V_i$$

$$V_i = 1\mu V \quad \text{[peak to peak]}$$

$$
\begin{aligned}
\therefore V_o &= A_{V_T} \times V_i \\
&= 7287.8 \times 1\mu V \\
&= \mathbf{7.287mV} \quad \text{[peak to peak]}
\end{aligned}
$$

### SIMULATED RESULTS

The above circuit is simulated in LTspice and results are presented below:

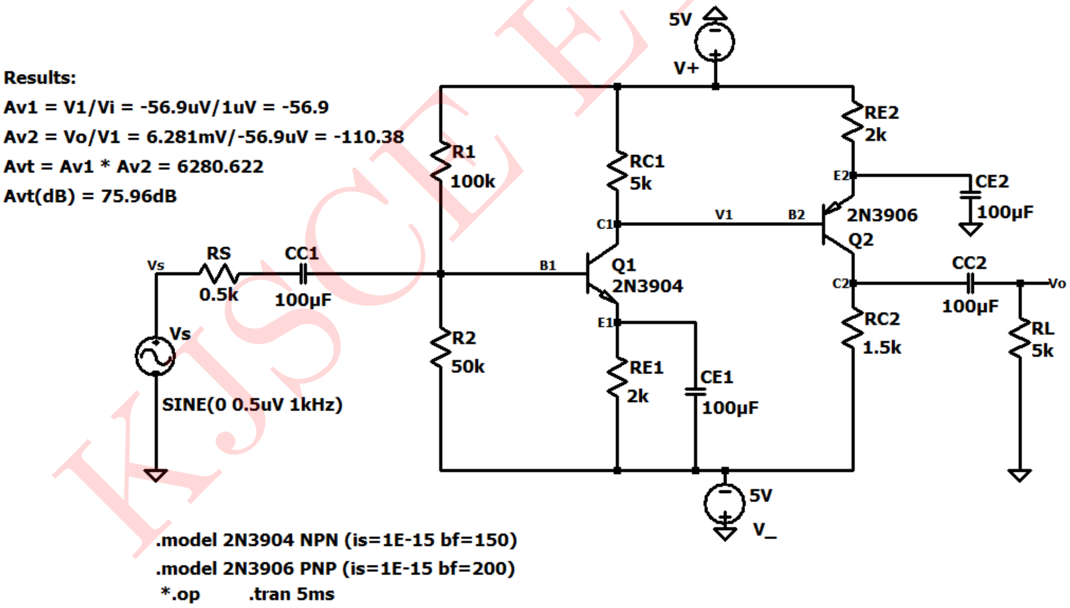


Figure 19: Circuit Schematic

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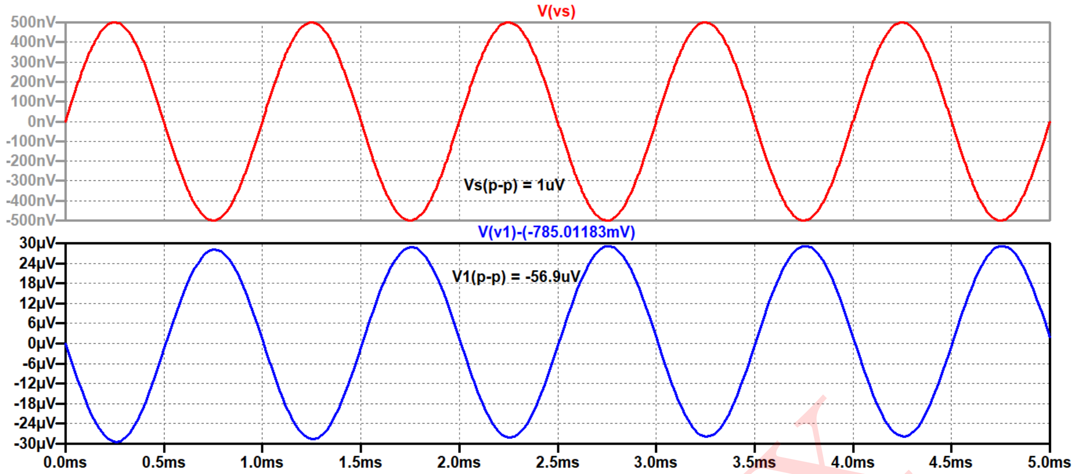


Figure 20: Input Output waveforms of 1st stage

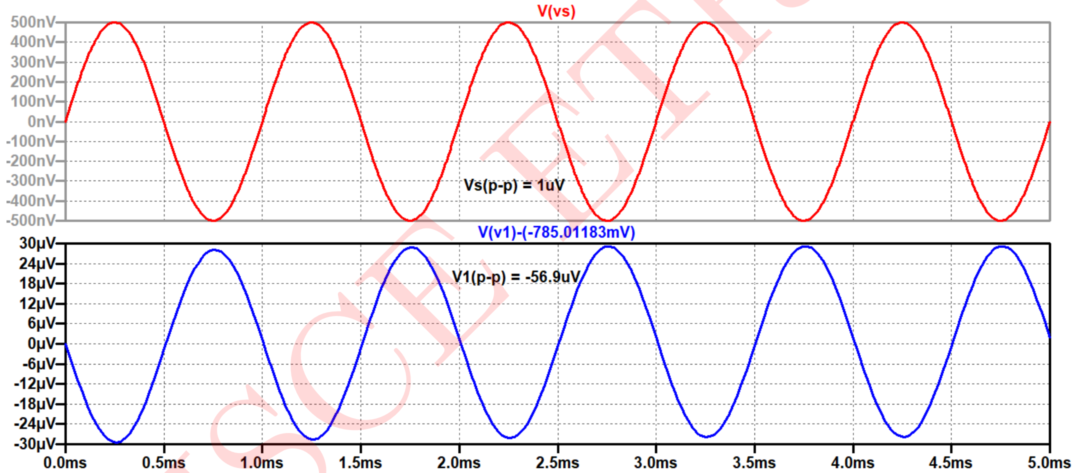


Figure 21: Input Output waveforms of 2nd stage

**Comparison of Theoretical and Simulated results:**

| Parameters | Theoretical | Simulated |
|---|---|---|
| $I_{B_1}$ | $7.84\mu A$ | $7.797\mu A$ |
| $I_{C_1}$, $I_{E_1}$ | $1.176mA$, $1.183mA$ | $1.169mA$, $1.177mA$ |
| $I_{B_2}$ | $12.72\mu A$ | $12.553\mu A$ |
| $I_{C_2}$, $I_{E_2}$ | $2.544mA$, $2.5575mA$ | $2.51mA$, $2.523mA$ |
| $V_{C_1}$ | $-0.815V$ | $-0.785V$ |
| $V_{C_2}$ | $-1.184V$ | $-1.2339V$ |
| $V_{E_1}$ | $-2.634V$ | $-2.645V$ |
| $V_{E_2}$ | $-0.115V$ | $-0.0465V$ |
| $V_{B_1}$ | $-1.934V$ | $-1.9265V$ |
| $V_{B_2}$ | $-0.815V$ | $-0.785V$ |
| $A_{V_T}$ in dB | 77.25dB | 75.96dB |
| $V_o$ [peak to peak] | $7.287mV$ | $6.281mV$ |

Table 3: Numerical 3

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