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LINEAR INTEGRATED CIRCUITS

PART-04

AC Analysis of BJT Differential Amplifier Circuit

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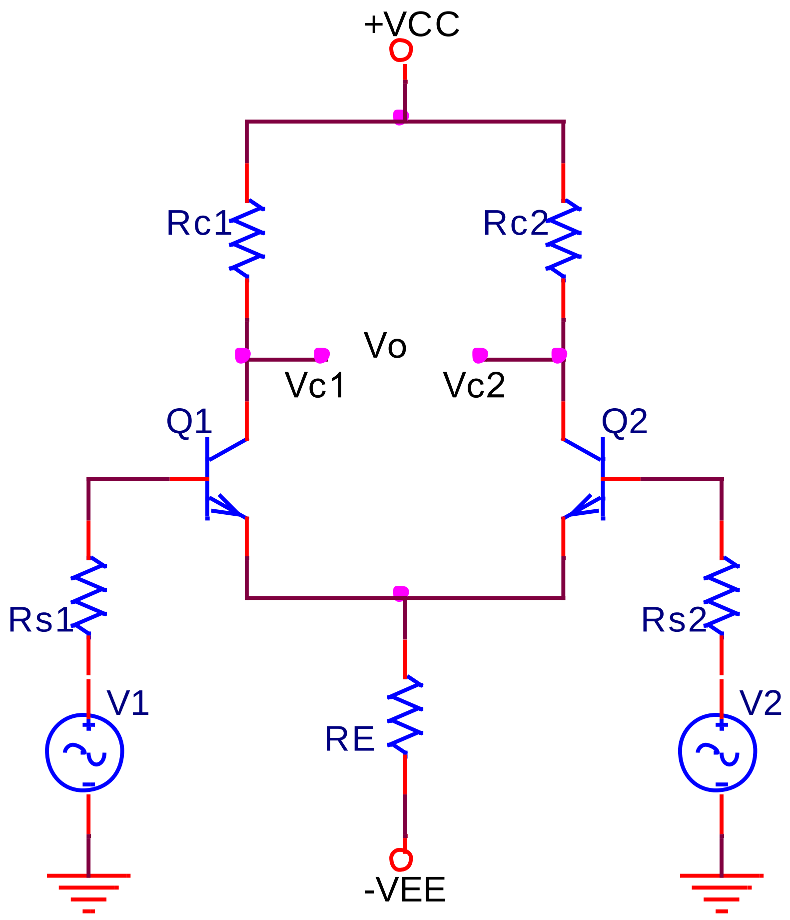
AC Analysis

AC analysis of a BJT Differential Amplifier involves determination of

1. Voltage Gain
2. Input Impedance
3. Output Resistance

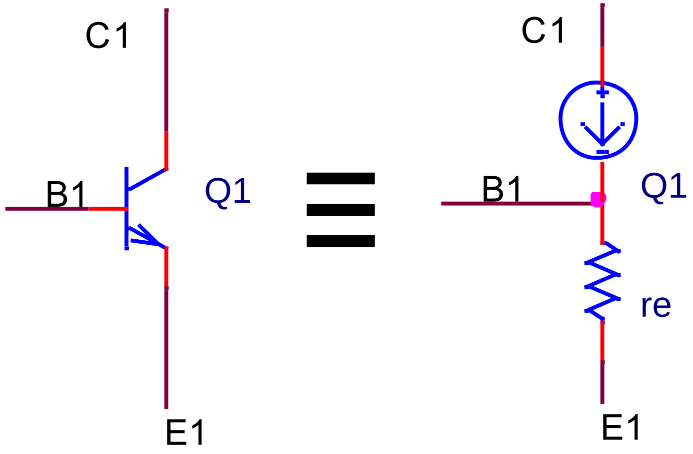
Dual Input Balanced Output Differential Amplifier

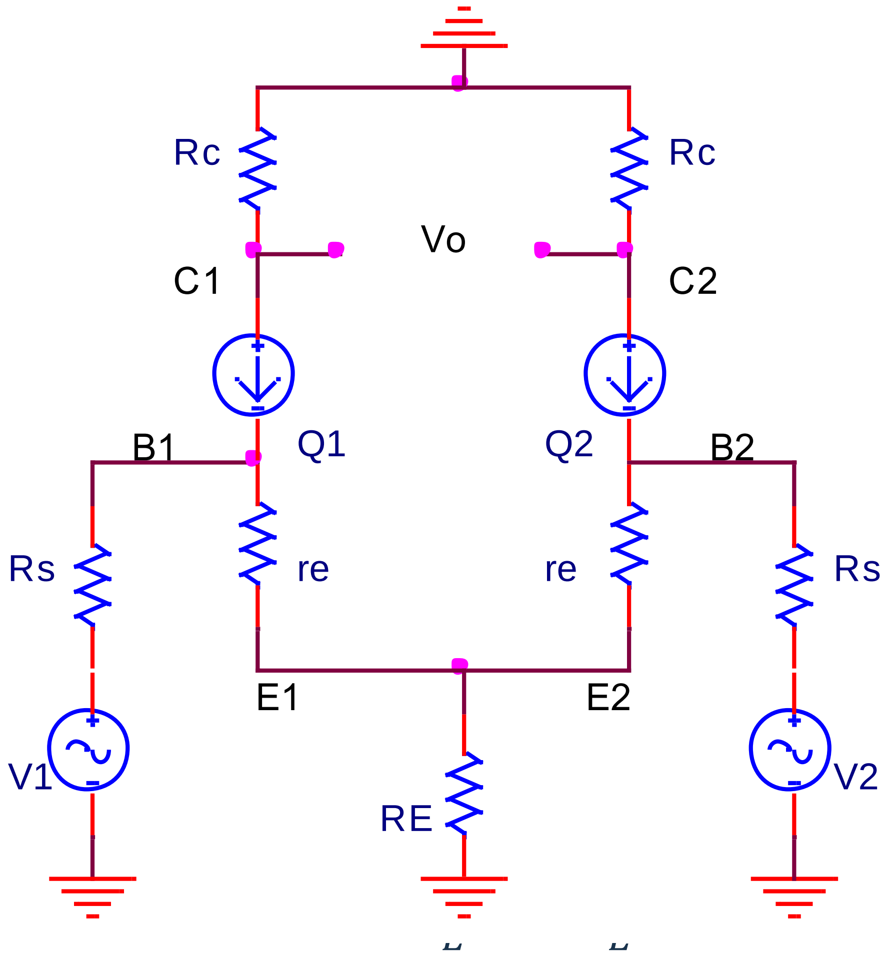


AC Analysis of Differential Amplifier

Important consideration for AC Analysis

1. Both Q_1 & Q_2 are identical BJTs
2. Resistances $R_{s1} = R_{s2} = R_s$ & $R_{C1} = R_{C2} = R_C$
3. DC supplies will be grounded
4. BJTs are replace with equivalent r-model





AC Analysis – Voltage Gain

Differential Voltage Gain $A_d = \frac{V_o}{V_1 - V_2}$

$$V_o = i_{c1}R_c - i_{c2}R_c$$

KVL in loop I: $V_1 = R_s i_{b1} + r_e i_{e1} + (i_{e1} + i_{e2})R_E$

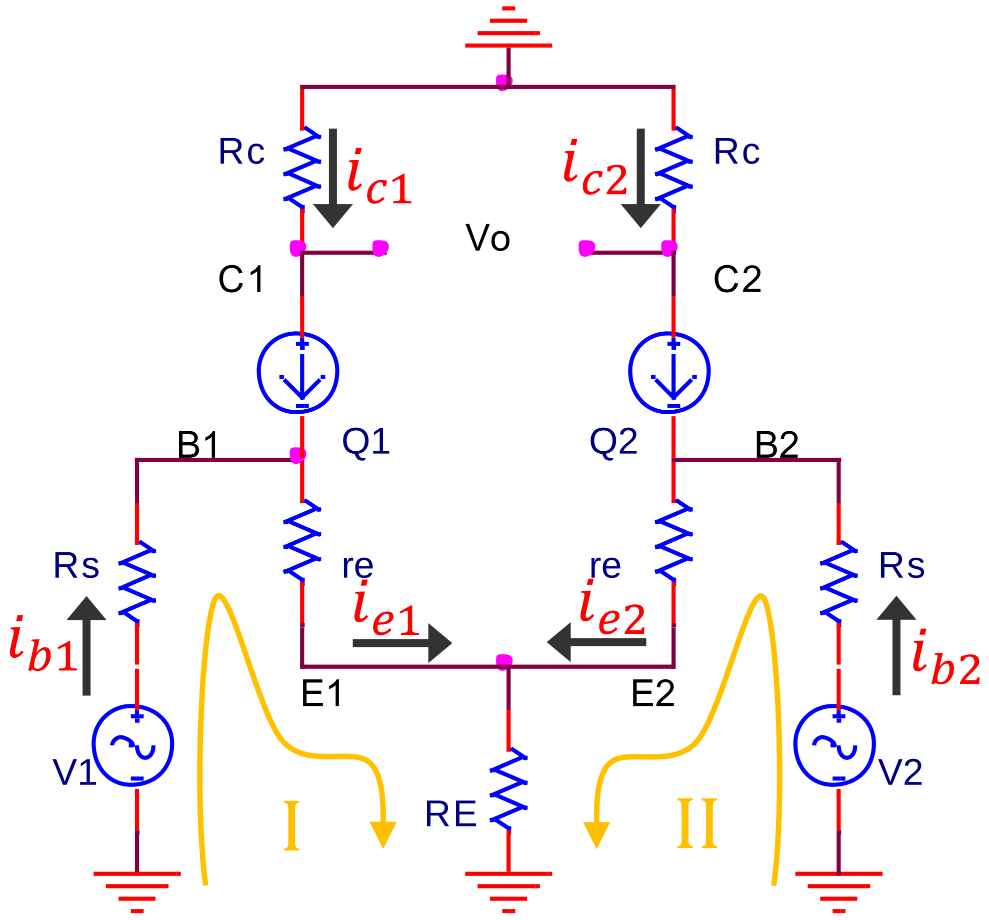
KVL in loop II: $V_2 = R_s i_{b2} + r_e i_{e2} + (i_{e1} + i_{e2})R_E$

Substitute $i_{b1} = \frac{i_{e1}}{\beta}$ and $i_{b2} = \frac{i_{e2}}{\beta}$

$$V_1 = R_s \frac{i_{e1}}{\beta} + r_e i_{e1} + (i_{e1} + i_{e2})R_E$$

$$V_1 = \left(\frac{R_s}{\beta} + r_e + R_E\right) i_{e1} + R_E i_{e2}$$

Similarly, $V_2 = R_E i_{e1} + \left(\frac{R_s}{\beta} + r_e + R_E\right) i_{e2}$



AC Analysis – Voltage Gain

Consider typical values $R_S/\beta = 50/100$. Let's ignore R_S/β as $R_S/\beta \ll R_E$ & r_e

$$(r_e + R_E)i_{e1} + R_E i_{e2} = V_1$$

$$R_E i_{e1} + (r_e + R_E)i_{e2} = V_2$$

Solve using **Crammer's Rule**

$$\begin{bmatrix} r_e + R_E & R_E \\ R_E & r_e + R_E \end{bmatrix} \begin{bmatrix} i_{e1} \\ i_{e2} \end{bmatrix} = \begin{bmatrix} V_1 \\ V_2 \end{bmatrix}$$

Determinant of resistance matrix

$$\Delta = \begin{vmatrix} r_e + R_E & R_E \\ R_E & r_e + R_E \end{vmatrix} = (r_e + R_E)^2 - R_E^2$$

$$\Delta_1 = \begin{vmatrix} V_1 & R_E \\ V_2 & r_e + R_E \end{vmatrix} = (R_E + r_e)V_1 - V_2 R_E$$

Current i_{e1} is given as

$$i_{e1} = \frac{\Delta_1}{\Delta} = \frac{(R_E + r_e)V_1 - V_2 R_E}{(r_e + R_E)^2 - R_E^2} = i_{c1}$$

$$\Delta_2 = \begin{vmatrix} r_e + R_E & V_1 \\ R_E & V_2 \end{vmatrix} = (R_E + r_e)V_2 - V_1 R_E$$

Current i_{e2} is given as

$$i_{e2} = \frac{\Delta_2}{\Delta} = \frac{(R_E + r_e)V_2 - V_1 R_E}{(r_e + R_E)^2 - R_E^2} = i_{c2}$$

AC Analysis – Voltage Gain

Output voltage $V_o = R_c(i_{c1} - i_{c2})$

Put values of i_{c1} and i_{c2}

$$V_o = R_c\left(\frac{(R_E + r_e)V_1 - R_E V_2}{(r_e + R_E)^2 - R_E^2} - \frac{(R_E + r_e)V_2 - R_E V_1}{(r_e + R_E)^2 - R_E^2}\right)$$

$$V_o = R_c\left(\frac{R_E V_1 + r_e V_1 - R_E V_2 - R_E V_2 - r_e V_2 + R_E V_1}{(r_e + R_E)^2 - R_E^2}\right)$$

$$V_o = R_c\left(\frac{2R_E V_1 + r_e V_1 - 2R_E V_2 - r_e V_2}{r_e^2 + 2R_E r_e + R_E^2 - R_E^2}\right)$$

$$V_o = R_c\left(\frac{(2R_E + r_e)V_1 - (2R_E + r_e)V_2}{r_e^2 + 2R_E r_e}\right)$$

$$V_o = R_c\left(\frac{(2R_E + r_e)(V_1 - V_2)}{r_e(r_e + 2R_E)}\right)$$

$$V_o = \frac{R_C}{r_e}(V_1 - V_2)$$

Finally, Voltage Gain the Differential Amplifier is given as

$$A_d = \frac{V_o}{V_1 - V_2} = \frac{R_C}{r_e}$$

AC Analysis – Input Resistance

Input Resistance at first source of a Dual Input Balanced Output Differential Amplifier are given as

$$R_{i1} = \left.\frac{V_1}{i_{b1}}\right|_{V_2=0} = \left.\frac{V_1}{i_{e1}/\beta}\right|_{V_2=0} = \left.\frac{\beta V_1}{i_{e1}}\right|_{V_2=0}$$

Putting the value of i_{e1}

$$R_{i1} = \left.\frac{\beta V_1}{\frac{(R_E + r_e)V_1 - V_2 R_E}{(r_e + R_E)^2 - R_E^2}}\right|_{V_2=0}$$

$$R_{i1} = \frac{\beta r_e V_1 (r_e^2 + 2R_E r_e + R_E^2 - R_E^2)}{(R_E + r_e)V_1}$$

$$R_{i1} = \frac{\beta r_e (r_e + 2R_E)}{R_E + r_e}$$

Since $(R_E \approx 3k) \gg (r_e \approx 30)$ therefore, $r_e + 2R_E \approx 2R_E$ and $r_e + R_E \approx R_E$.

Finally, input resistance is given as

$$R_{i1} = 2\beta r_e$$

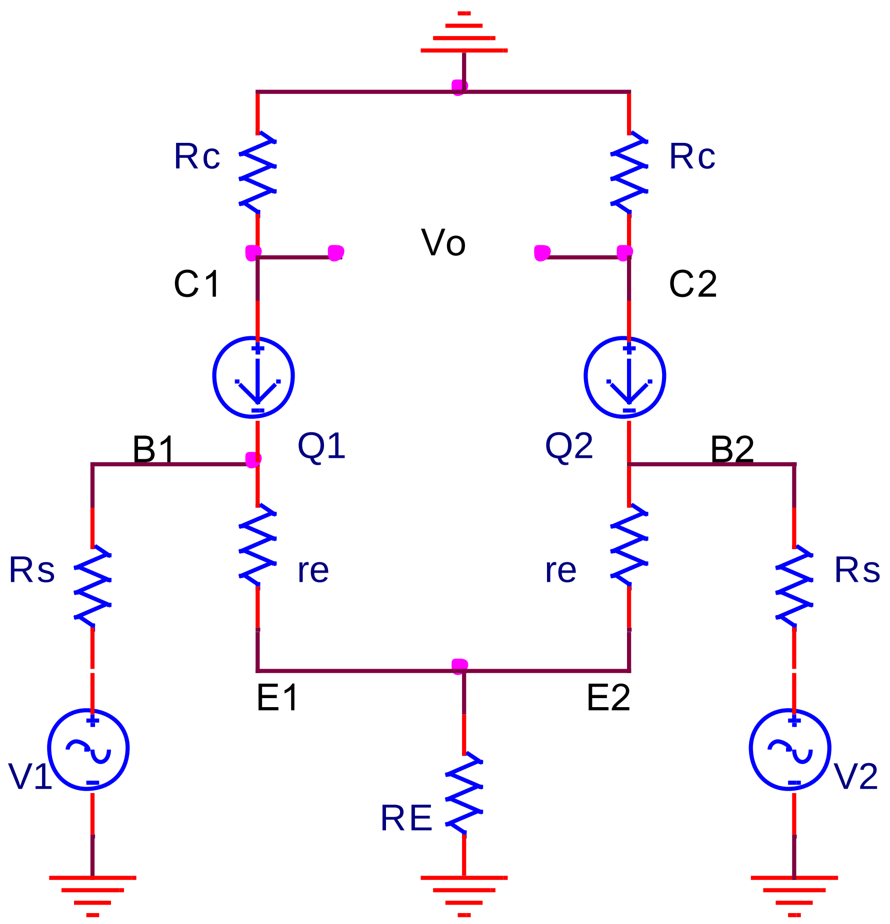
Similarly, Input Resistance at second input terminal is given as

$$R_{i2} = \left.\frac{V_2}{i_{b2}}\right|_{V_1=0} = \frac{\beta r_e (r_e + 2R_E)}{R_E + r_e} = 2\beta r_e$$

AC Analysis – Output Resistance & Current Gain

Output Resistance is measured at the collector terminal with respect to ground

$$R_{o1} = R_{o2} = R_C$$

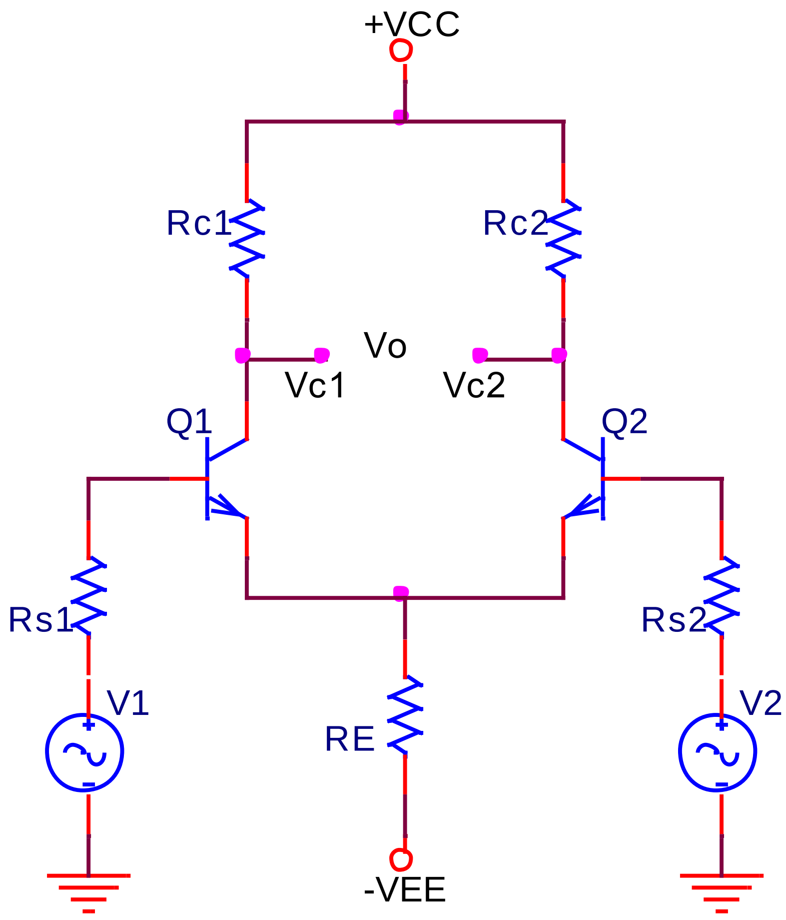


Current Gain of a Differential Amplifier is undefined.

Differential Amplifier is generally used as Voltage Amplifier and not as Current or Power Amplifier.

Numerical Problem

A Differential Amplifier with has $R_C = 2.2k\Omega$, $R_E = 4.7k\Omega$, $R_{S1} = R_{S2} = 50\Omega$, $V_{CC} = +10V$, $V_{EE} = -10V$, $\beta = 100$ and $V_{BE} = 0.7$. Determine its (a) Voltage Gain (b) Input Resistance (c) Output Resistance



Differential Voltage Gain formula is

$$A_d = \frac{V_o}{V_d} = \frac{R_C}{r_e}$$

However, $r_e = \frac{25mV}{I_E}$ at room temperature. But $I_E = ?$

Numerical Problem

During DC Analysis we following expression to determine I_E

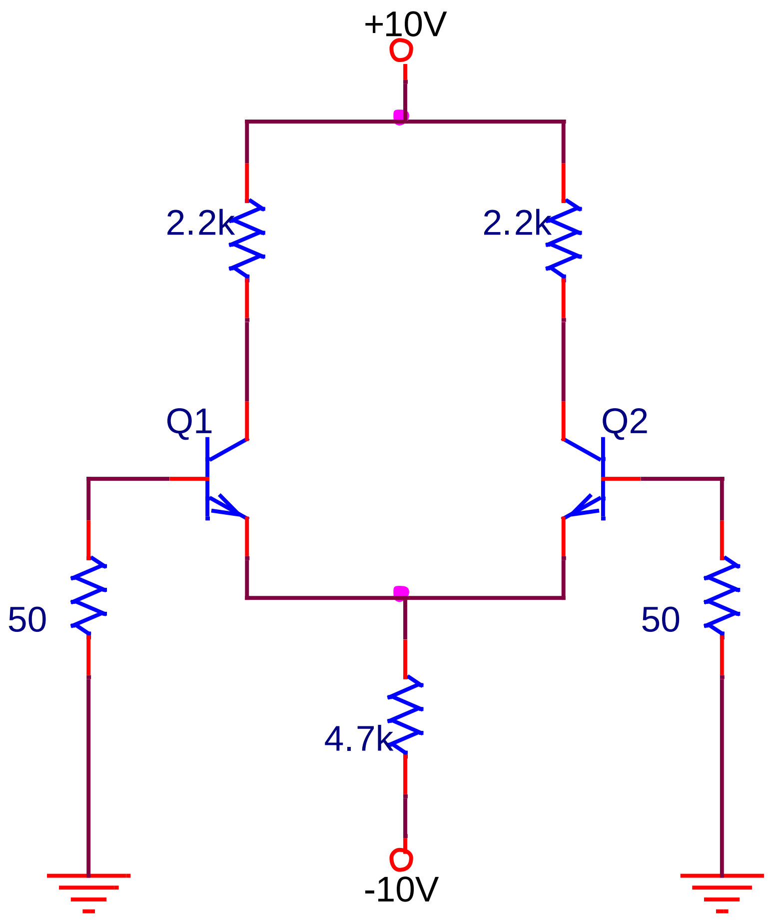
$$I_C = \frac{V_{EE} - V_{BE}}{(R_s/\beta + 2R_E)} = I_E$$

Putting given values

$$I_E = \frac{10 - 0.7}{(50/100 + 2 * 4.7k)} = \mathbf{0.989mA}$$

Further,

$$r_e = \frac{25mV}{I_E} = \frac{25mV}{0.989mA} = \mathbf{25.3\Omega}$$



Numerical Problem

Using Voltage Gain formula

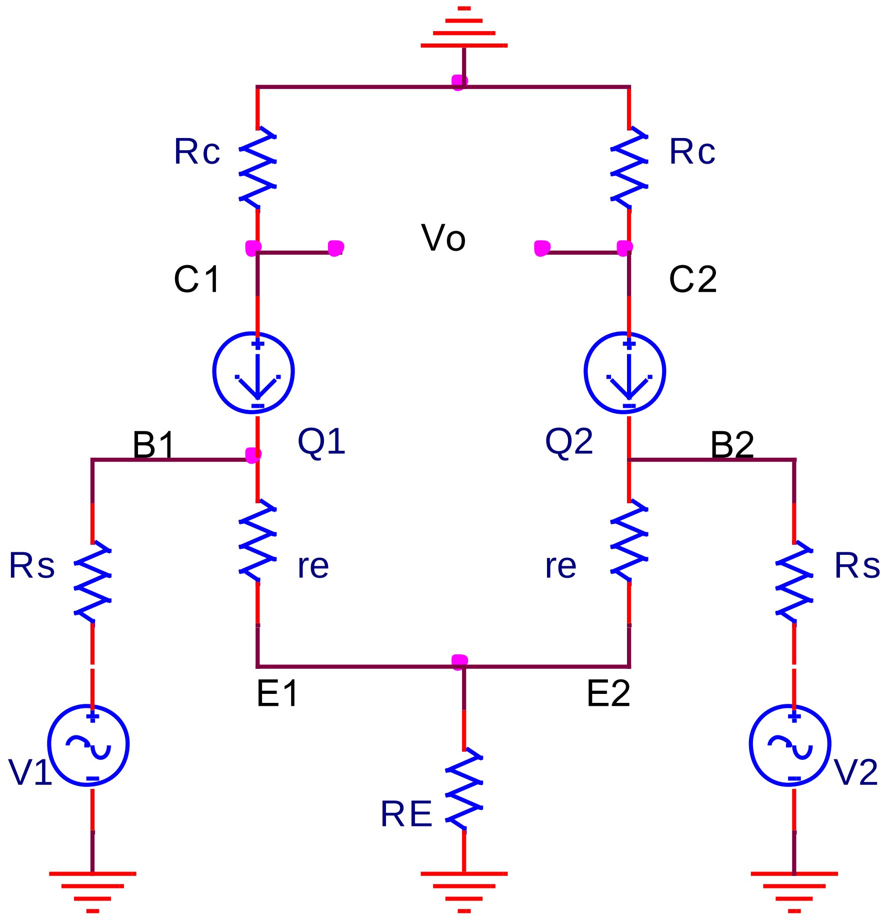
$$A_d = \frac{R_C}{r_e} = \frac{2.2k\Omega}{25.3\Omega} = \mathbf{86.96}$$

Input Resistances are given as

$$R_{i1} = R_{i2} = 2\beta r_e = 2 * 100 * 25.3\Omega = \mathbf{5.06k\Omega}$$

Output Resistances are given by

$$R_{o1} = R_{o2} = R_C = \mathbf{2.2k\Omega}$$



Thank You

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