Chapter 4

Differential and Multistage IC Amplifiers

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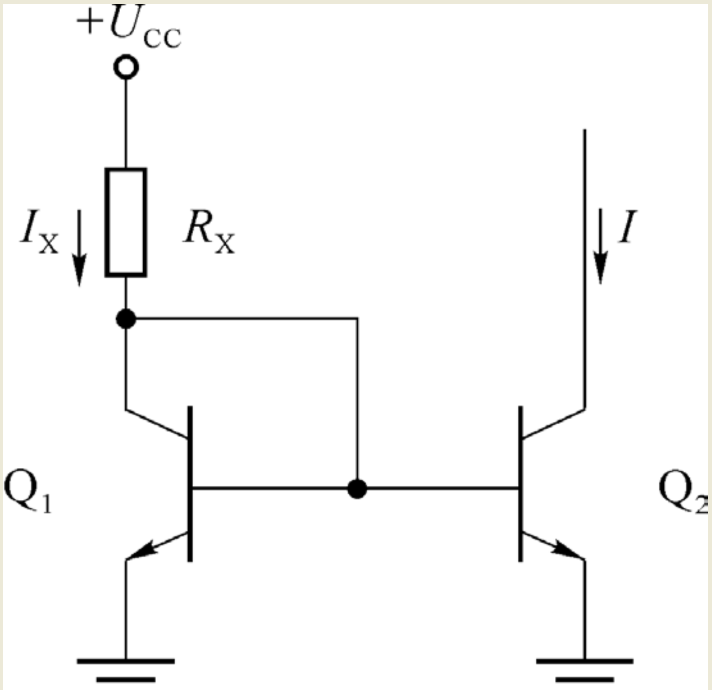
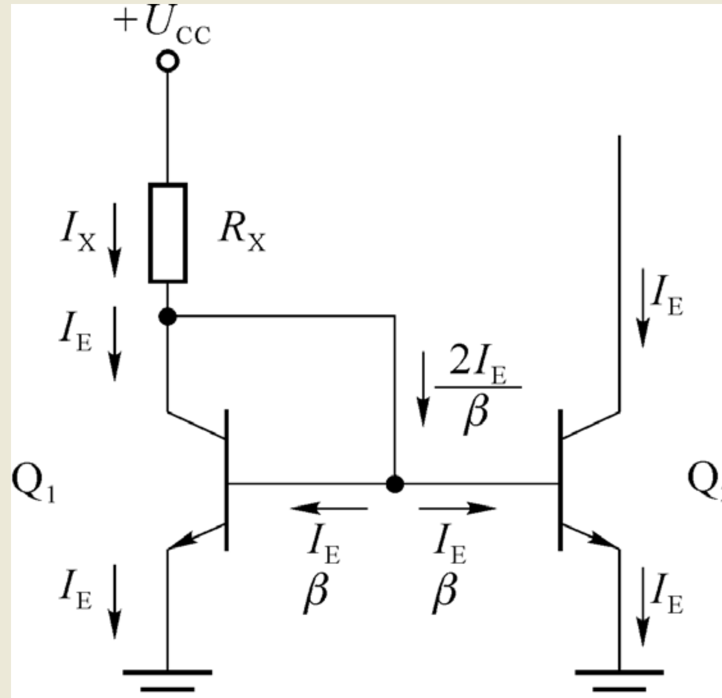
4.1 Current Sources

Current Source circuits can provide constant current in Integrated Circuits.



Typical Current Circuit



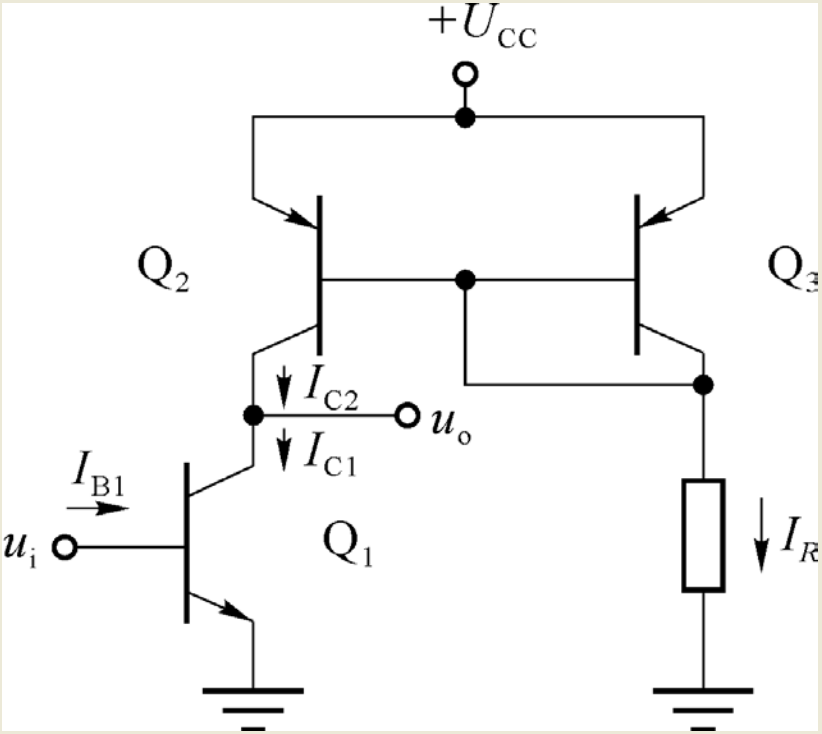
$$I_X = I_E + 2I_B = I_E + 2\frac{I_E}{\beta} = \frac{\beta+2}{\beta} I_E$$

$$I_E = \frac{\beta}{\beta+2} I_X \approx I_X = \frac{U_{CC} - U_{BE}}{R_X}$$

I_x is determined by U_{cc} and R_x.

Application of Current Sources

Current Source circuits can be used as the active load of amplifier.



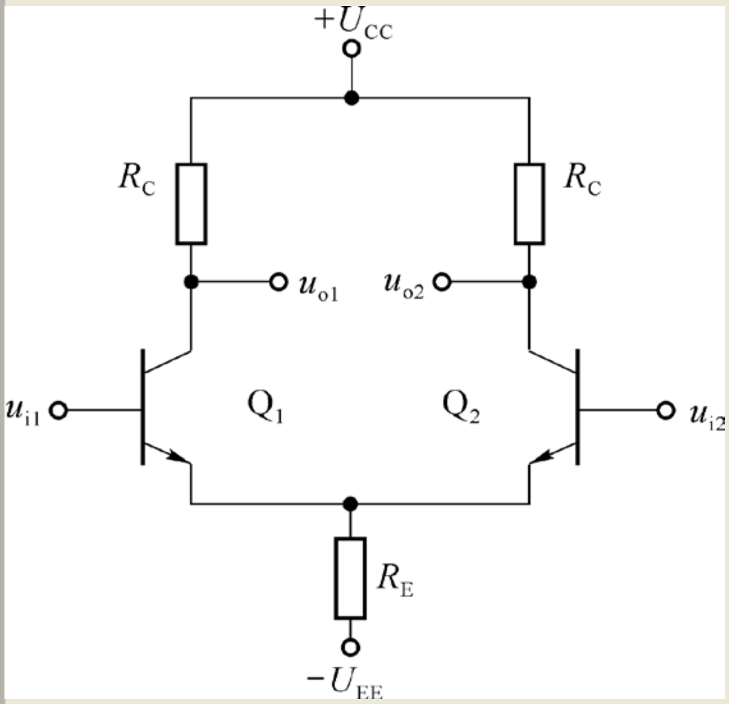
DC Analysis:

$$I_X = \frac{U_{CC} - U_{BE}}{R_X}$$

$$I_{C1} = I_{C2} = \frac{1}{1 + 2/\beta} I_X$$

The circuit doesn't need high voltage supply. If the U_{CC} and R_X are appropriately matched, the quiescent operation point of the circuit could be acquired.

4.2 Differential Amplifiers



Basic differential amplifier

1. A fundamental building block of analog ICs.

2. Identical transistor characteristics of the differential-pair

3. Two possible inputs and two possible outputs:

(1) **Double input**: If two opposite-polarity input signals are applied, the operation is referred to as “double-input” or “differential-mode input”.

(2) **Single input**: If an input signal is applied to either input with the other input connected to ground, the operation is referred to as “single-input”.

(3) **Common-mode**: If the same input is applied to both inputs, the operation is call “common-mode input”.

4. High gain, high input impedance, and low output impedance

Differential Input: $U_d = U_{i1} - U_{i2}$

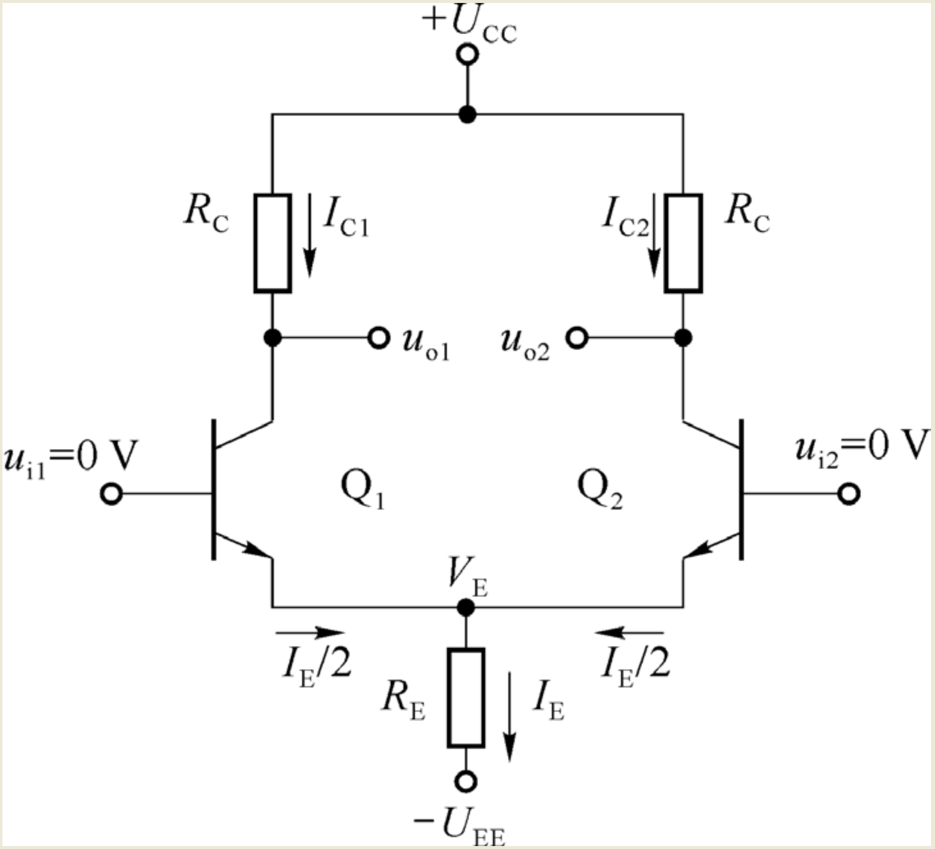
Common Input: $U_c = \frac{1}{2}(U_{i1} + U_{i2})$

$\Leftrightarrow$

$U_{i1} = U_c + \frac{1}{2} U_d$

$U_{i2} = U_c - \frac{1}{2} U_d$

DC Analysis



DC Bias:

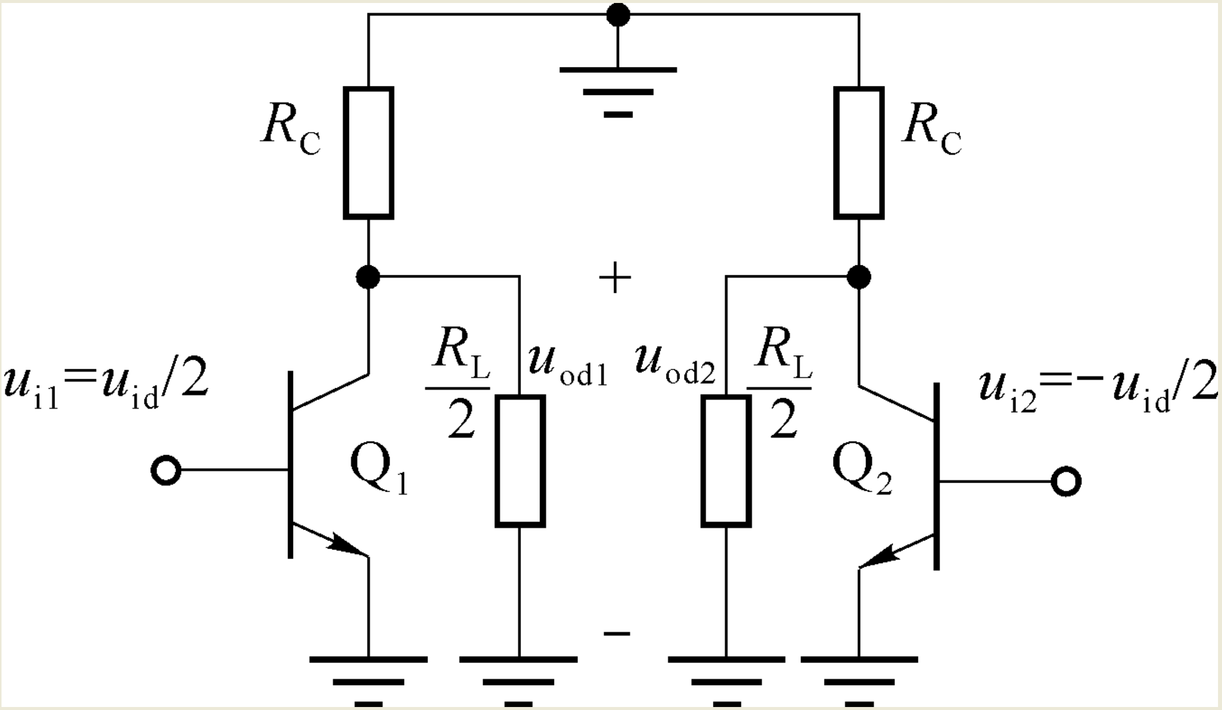
$$U_E = U_B - U_{BE} = 0\text{V} - 0.7\text{V} = -0.7\text{V}$$

$$I_E = \frac{U_E - (-U_{EE})}{R_E} = \frac{U_{EE} - 0.7\text{V}}{R_E}$$

$$I_{C_1} = I_{C_2} \approx \frac{1}{2} I_E$$

$$U_{C_1} = U_{C_2} = U_{CC} - I_C R_C = U_{CC} - \frac{1}{2} I_E R_C$$

AC Small-Signal Equivalent Circuit Analysis



AC network of the differential amplifier

AC Small-Signal Equivalent Circuit Analysis

AC Analysis of differential mode: *Using the half-circuit method*.

1. For the double output situation:

The half-circuit voltage gain: $A_{ud1} = -\frac{R_L'}{r_e}$, $R_L' = R_C \parallel (R_L/2)$

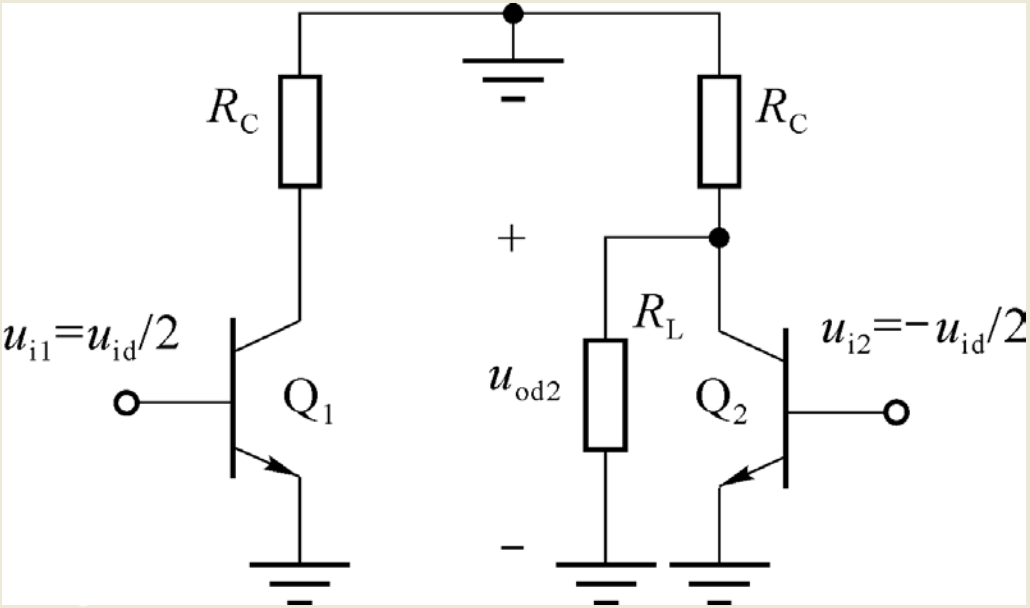
For the whole circuit: $A_{ud} = \frac{U_o}{U_i} = \frac{U_{od1} - U_{od2}}{U_{i1} - U_{i2}} = \frac{2U_{od1}}{2U_{i1}} = \frac{U_{od1}}{U_{i1}} = A_{ud1}$

2. For the single output situation:

$$A_{ud1} = \frac{U_{od1}}{U_{id}} = -\frac{1}{2}\frac{R_L'}{r_e}$$

$$A_{ud2} = \frac{U_{od2}}{U_{id}} = \frac{1}{2}\frac{R_L'}{r_e}$$

$$R_L' = R_C \parallel R_L$$



AC Small-Signal Equivalent Circuit Analysis

AC Analysis of differential mode:

Input impedance of differential-mode:

$$Z_{id} = \frac{U_{id}}{I_{id}} = \frac{U_{id}}{I_{b1}} = 2\beta r_e$$

Output impedance of differential-mode:

The output impedance of double-end output is:

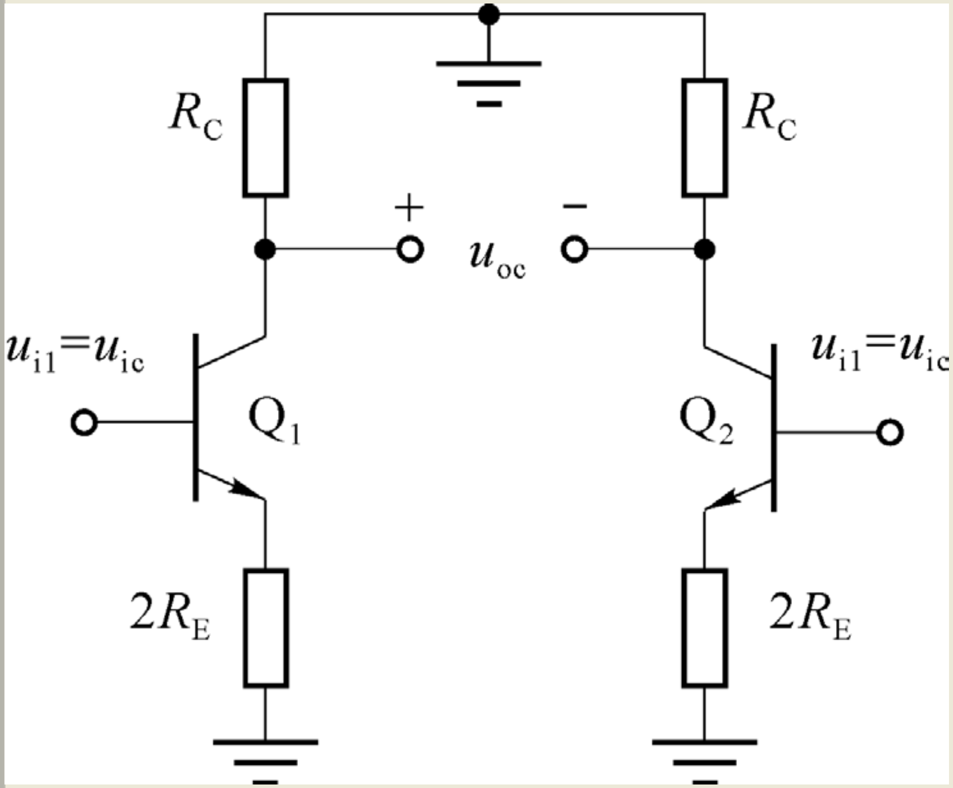
$$Z_{od} = 2R_{\mathrm{C}}$$

The output impedance of single-end output is:

$$Z_{od1} = Z_{od2} = R_{\mathrm{C}}$$

AC Small-Signal Equivalent Circuit Analysis

AC Analysis of common mode:



AC network of common-mode

For the double-output:

The voltage gain: $A_{uc} = 0$

For the single-output, using half-circuit:

$$A_{uc1} = \frac{u_{oc1}}{u_{ic}} = -\frac{I_b \beta R_L'}{I_b\left(\beta r_e + (\beta+1)2R_E\right)} \approx -\frac{R_L'}{2R_E}$$

$$A_{uc2} = \frac{u_{oc2}}{u_{ic}} = -\frac{I_b \beta R_L'}{I_b\left(\beta r_e + (\beta+1)2R_E\right)} \approx -\frac{R_L'}{2R_E}$$

$$R_L' = R_C \parallel R_L$$

Usually $R_L' \ll 2R_E$

therefore, $A_{uc1} = A_{uc2} \ll 1$

.

Differential and Common-mode Operation

CMRR:

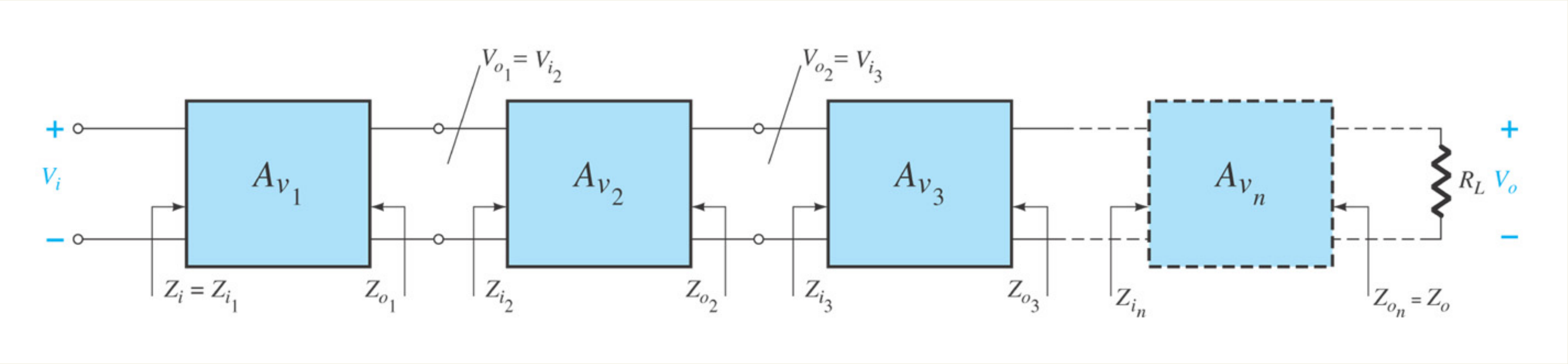
Any signal that is common to both inputs will be cancelled. A measure of the ability to cancel out common signals is called CMRR (common-mode rejection ratio).

$$K_{CMR} = \frac{A_{ud}}{A_{uc}}$$

$$K_{CMR}(\log) = 20\lg\frac{A_{ud}}{A_{uc}}(dB)$$

4.3 Multistage Amplifiers

- The output of one amplifier is the input to the next amplifier.
- The overall voltage gain is determined by the product of gains of the individual stages.



Multistage Amplifiers

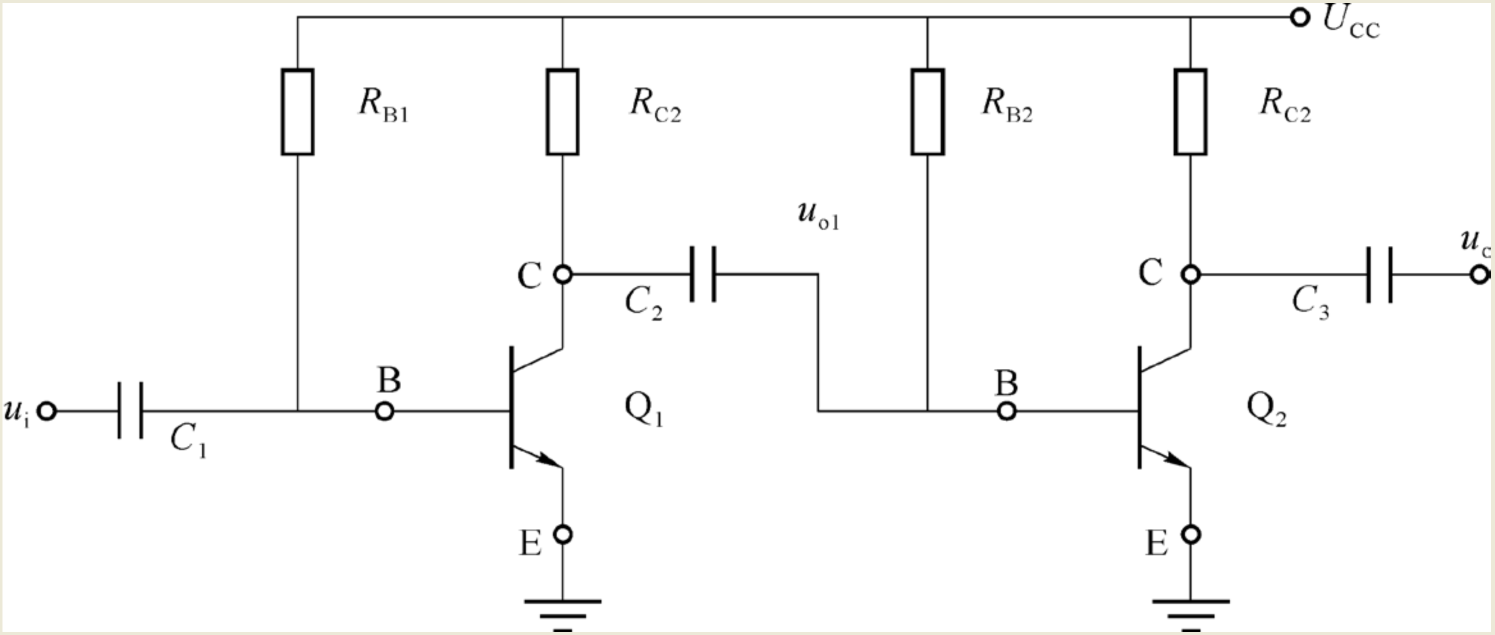
$$\mathbf{Z_i = Z_{i_1} \qquad Z_o = Z_{o_n}}$$

$$\mathbf{A}_u = \mathbf{A}_{u_1} \cdot \mathbf{A}_{u_2} \cdot \mathbf{A}_{u_3} \cdots \mathbf{A}_{u_n} \qquad \mathbf{A}_{u_1}, \mathbf{A}_{u_2}, \mathbf{A}_{u_3}, \cdots, \mathbf{A}_{u_n}$$ **are loaded gains.**

Coupling Modes

1. RC coupling mode:

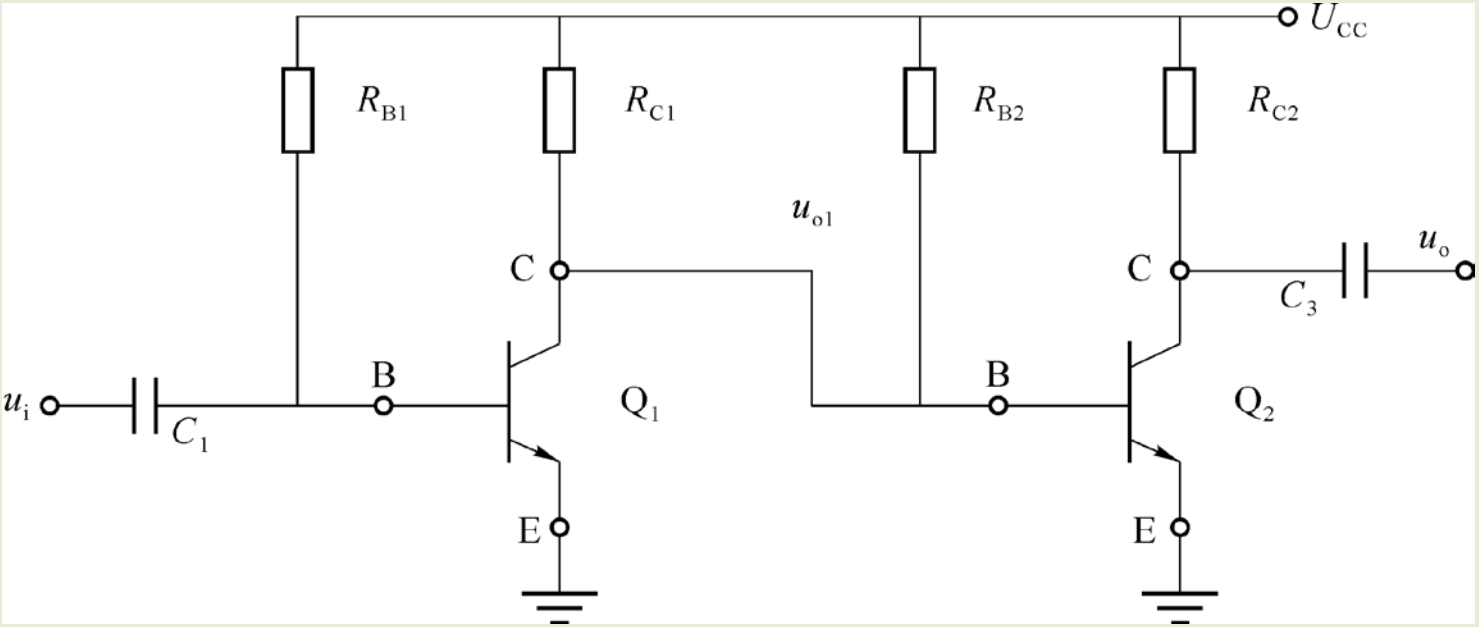
- The DC bias circuits are isolated from each other by the coupling capacitors.
- The DC calculations are independent of the cascading.
- The AC calculations for gain and impedance are interdependent.
- But big capacitor is difficult to achieve in IC, RC-coupling mode can hardly used in IC.



Coupling Modes

2. Direct coupling mode:

- Direct coupling mode between the former and latter stage is directly or resistor connected, the dc networks of each stage are also connected.
- The operation point of each stage is influenced by each other and the zero input drifting is also easily produced.
- Direct connection coupling mode is the amplifying ability for both ac input signals and the dc signals or signals varying slowly.
- Don’t need the capacitor, which is convenient for the circuit integration.



Key Points

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    - Structure and Typical application
- Differential Amplifiers
    - Structure of Differential Pairs
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