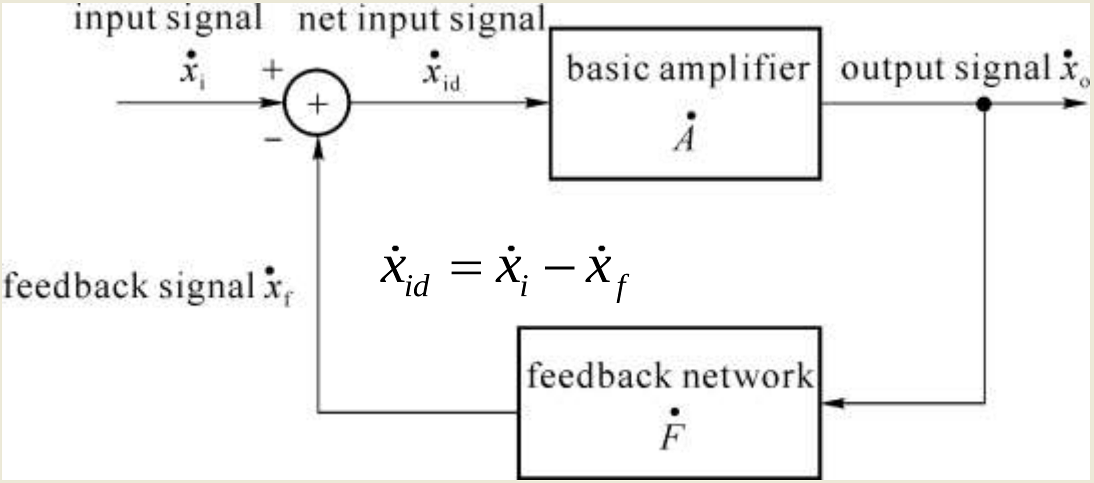
Chapter 6
Feedback Amplifiers

6.1 Feedback Concepts

Feedback consists of ***returning*** part of the ***output*** signal of a system to the ***input*** side, and ***summing*** or ***subtraction*** with the original input signal to form a ***net*** input signal to the amplifier.

A feedback amplifier is a *close loop*:

- **Basic amplifier without feedback (also termed as *open loop*)**
- **Feedback path from output to input**
- ***Sampling* of output signals**
- ***Superimposition* of feedback signal and input signal**



6.1 Feedback Concepts

Feedback types:

Be identified by ***analyzing instantaneous polarities*** for a network

Negative feedback

- **The feedback signal is of opposite polarity to the input signal causing the net input signal be *reduced* compared to the original input signal**
- **Typical application: to *improve circuit features***

Positive feedback

- **The feedback signal is of same polarity to the input signal causing the net input signal be *increased***
- **Typical application: Oscillator**

Be identified by ***analyzing DC and AC equivalent network***

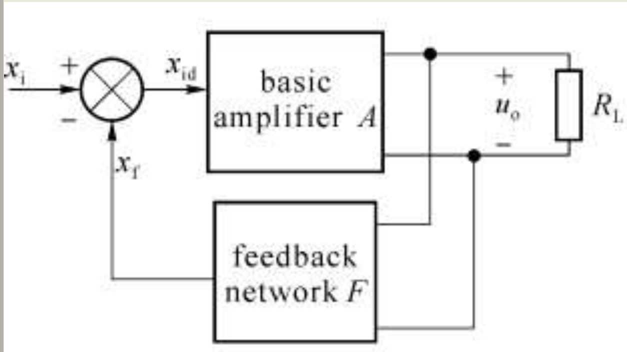
DC feedback

- **Feedback network existing in DC Networks introduces DC feedback**
- ***Improve the Quiescent point***

AC feedback

- **Feedback network existing in AC Networks introduces AC feedback**
- ***Improve AC characteristics of amplifiers***

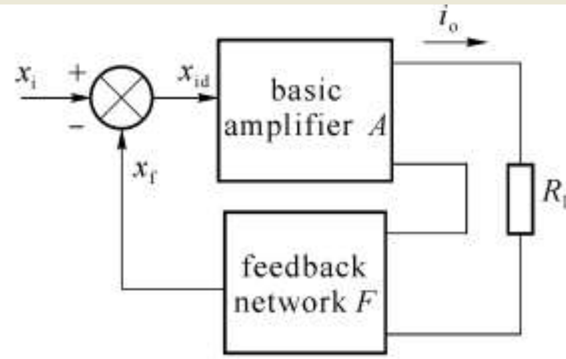
6.2 Negative Feedback Amplifiers



(a) samples the output voltage

Voltage feedback

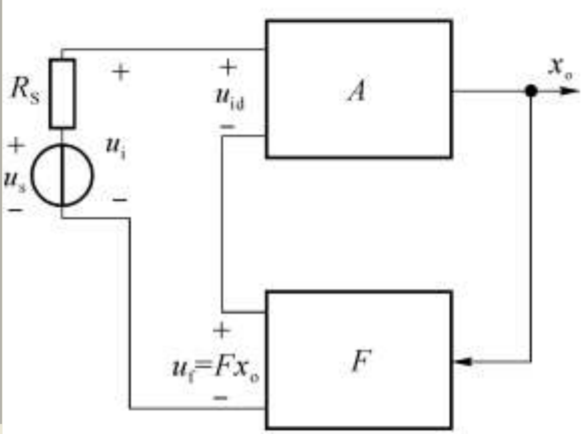
$$x_o \Rightarrow u_o$$



(b) samples the output current

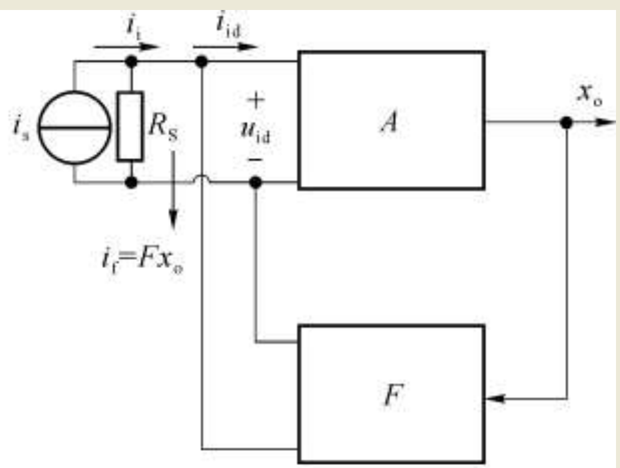
Current feedback

$$x_o \Rightarrow i_o$$



Series mixing

$$x_i, x_{id}, x_f \Rightarrow u_i, u_{id}, u_f$$



Parallel mixing

$$x_i, x_{id}, x_f \Rightarrow i_i, i_{id}, i_f$$

How to identify *voltage* feedback or *current* feedback?

Negative feedback amplifier types:

(1) voltage-series

(2) voltage-parallel

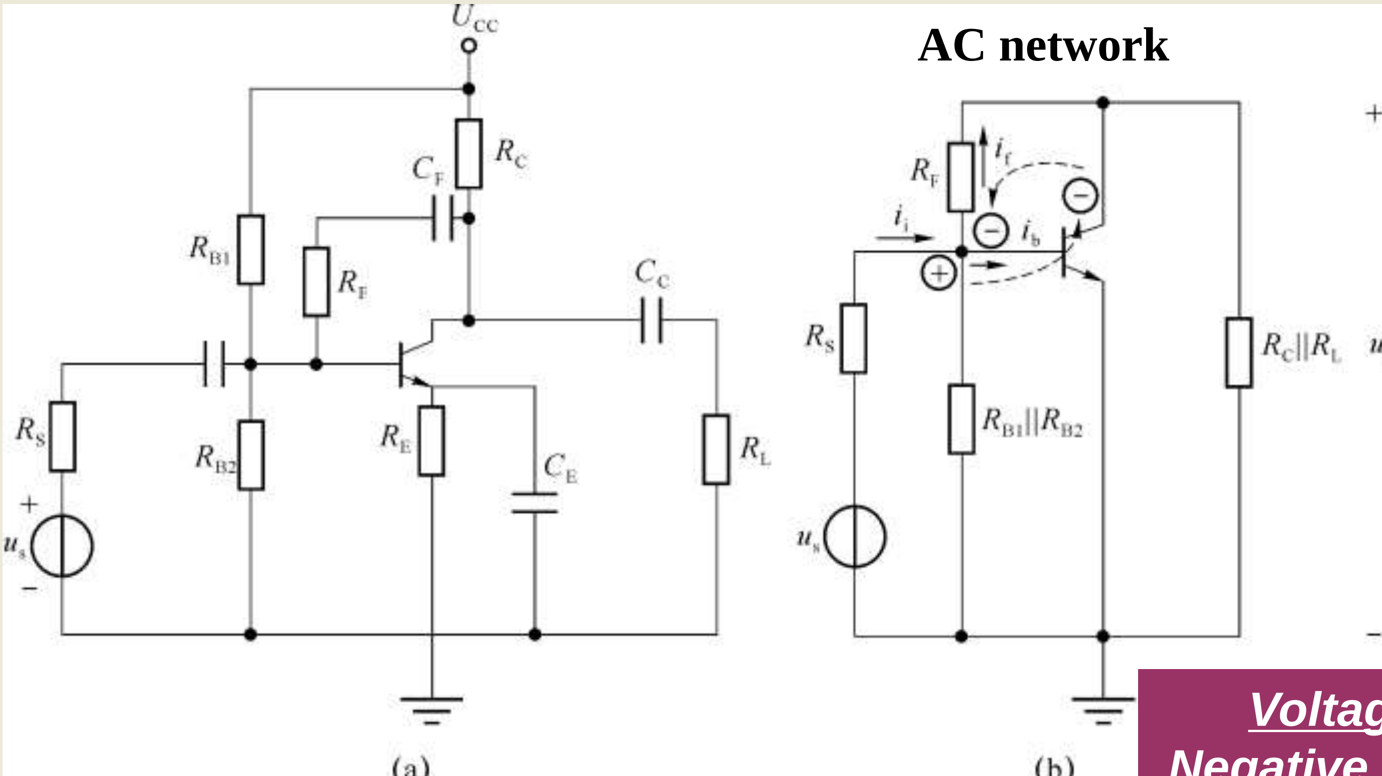
(3) current-series

(4) current-parallel

How to identify *parallel* or *series* mixing?

Examples

Example 6.2: **A feedback amplifier is illustrated in Figure (a), determine the polarity of AC feedback and if it is negative feedback, identify its specific type.**



(a) (b)

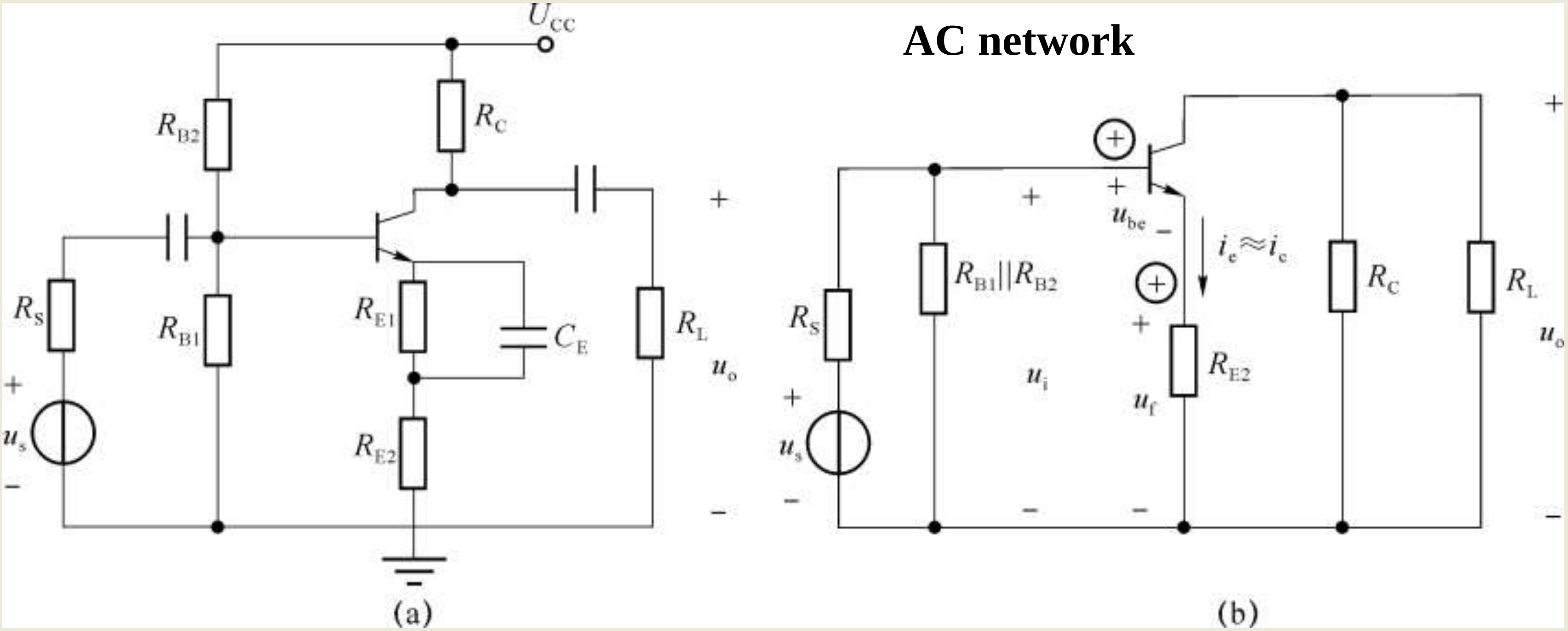
Voltage Parallel Negative AC Feedback

To identify voltage feedback and current feedback, a simple test is to ***Short-circuit the load*** to see whether the feedback signal vanishes.

In parallel mixing, the feedback signal and the input signals are connected ***at the same input terminal***.

Examples

Example 6.3: A feedback circuit is shown in Figure (a), determine the polarity of AC feedback. If it is a negative feedback, identify its specific type.

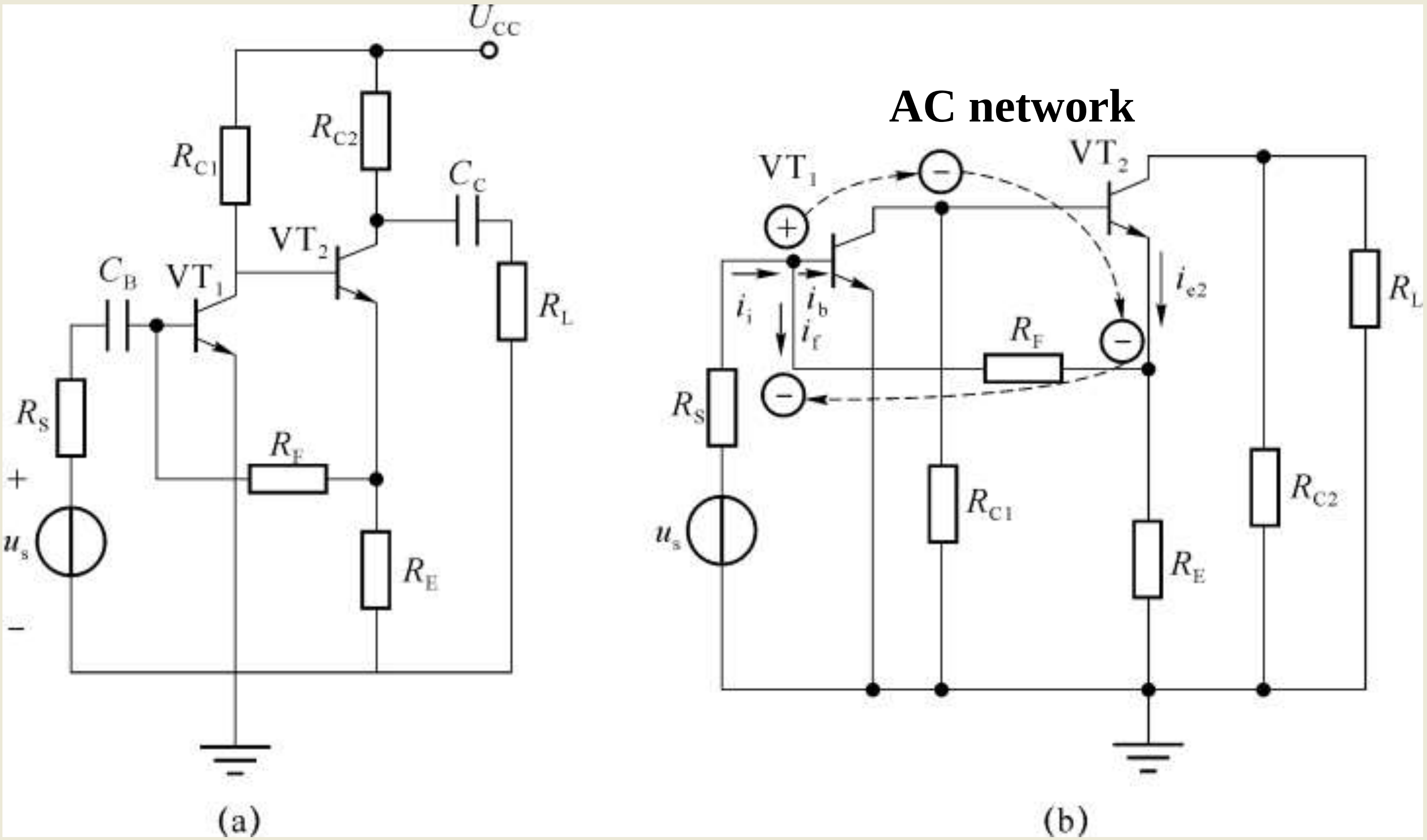


Current Series Negative AC Feedback

In series mixing, the feedback signal and the input signal are connected *at two input terminals separately*, and combined by voltage signals.

Examples

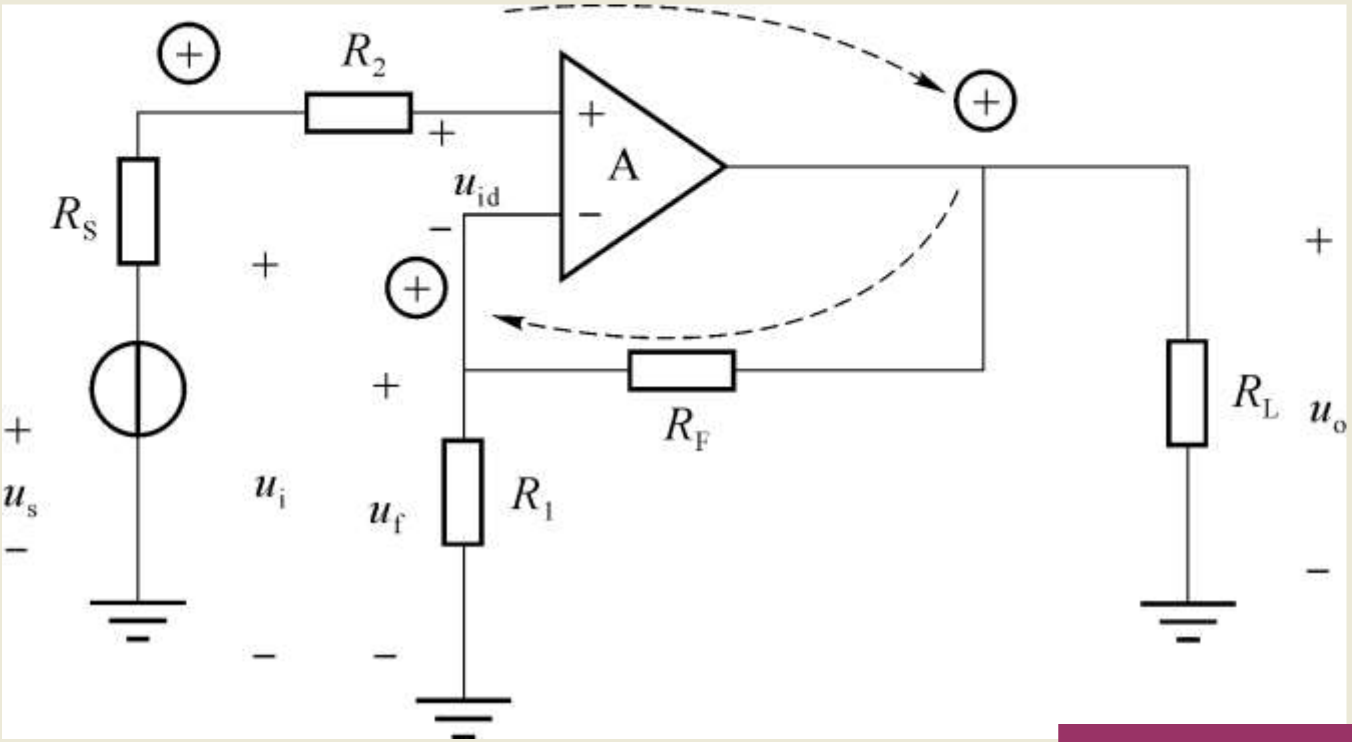
Example 6.5： **A feedback circuit is shown in Figure (a), determine the polarity of AC feedback. If it is a negative feedback, identify its specific type .**



Current Parallel Negative AC Feedback

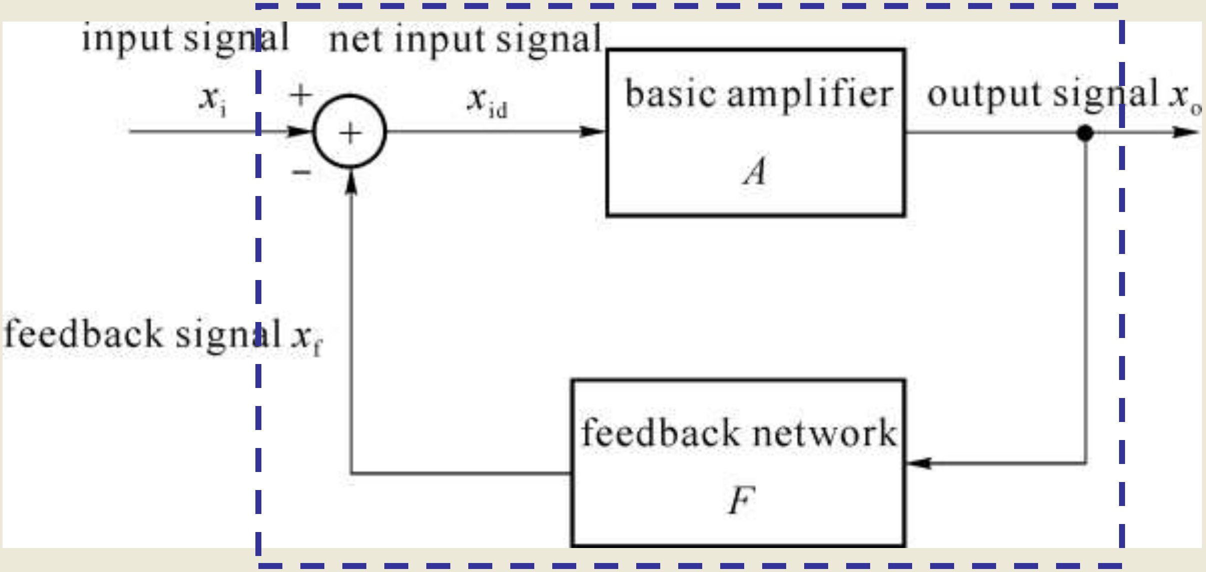
Examples

Example 6.4: **A feedback circuit is shown in Figure (a), determine the polarity of AC feedback. If it is a negative feedback, identify its specific type.**



Voltage Series Negative AC Feedback

6.2.2 Fundamental Formulations for Negative Feedback Amplifiers



Negative Feedback Amplifier (close loop)

The *net* input signal to the *basic* amplifier: $x_{id} = x_i - x_f$

The *open-loop* gain of the *basic* amplifier: $A = \dfrac{x_o}{x_{id}}$

The feedback coefficient: $F = \dfrac{x_f}{x_o}$

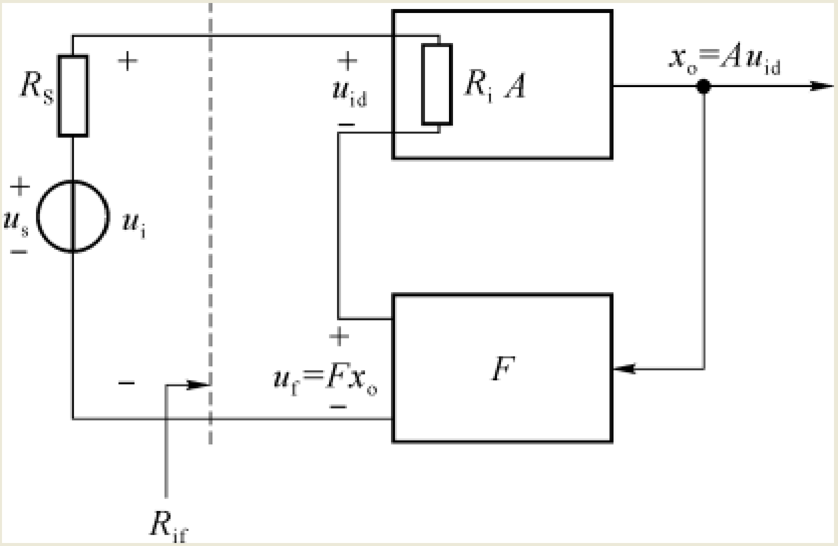
The gain with feedback (the *closed-loop* gain):

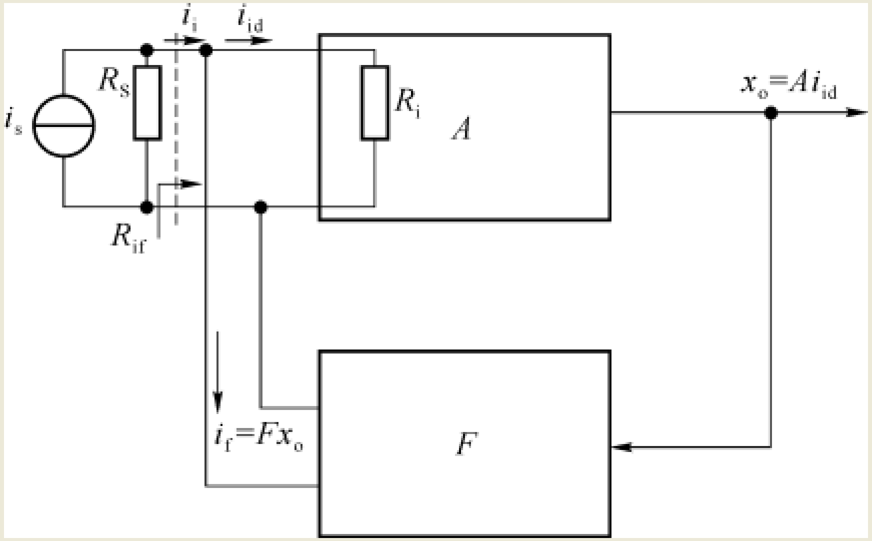
$$A_f = \frac{x_o}{x_i} = \frac{x_o}{x_{id} + x_f} = \frac{x_o}{x_{id} + AFx_{id}} = \frac{1}{1+AF} \cdot \frac{x_o}{x_{id}} = \frac{A}{1+AF}$$

For an amplifier with ***strong negative feedback*** ($AF >> 1$) , $A_f \approx \dfrac{1}{F}$

6.3 Effect of Negative Feedback

6.3.1 Input Impedance with Feedback





Series mixing

The closed-loop input resistance:

$$R_{if} = \frac{u_i}{i_i} = \frac{u_{id} + u_f}{i_i} = \frac{u_{id} + AFu_{id}}{i_i} = (1 + AF)R_i$$

Negative ***series*** feedback ***increases*** input resistance

Parallel mixing

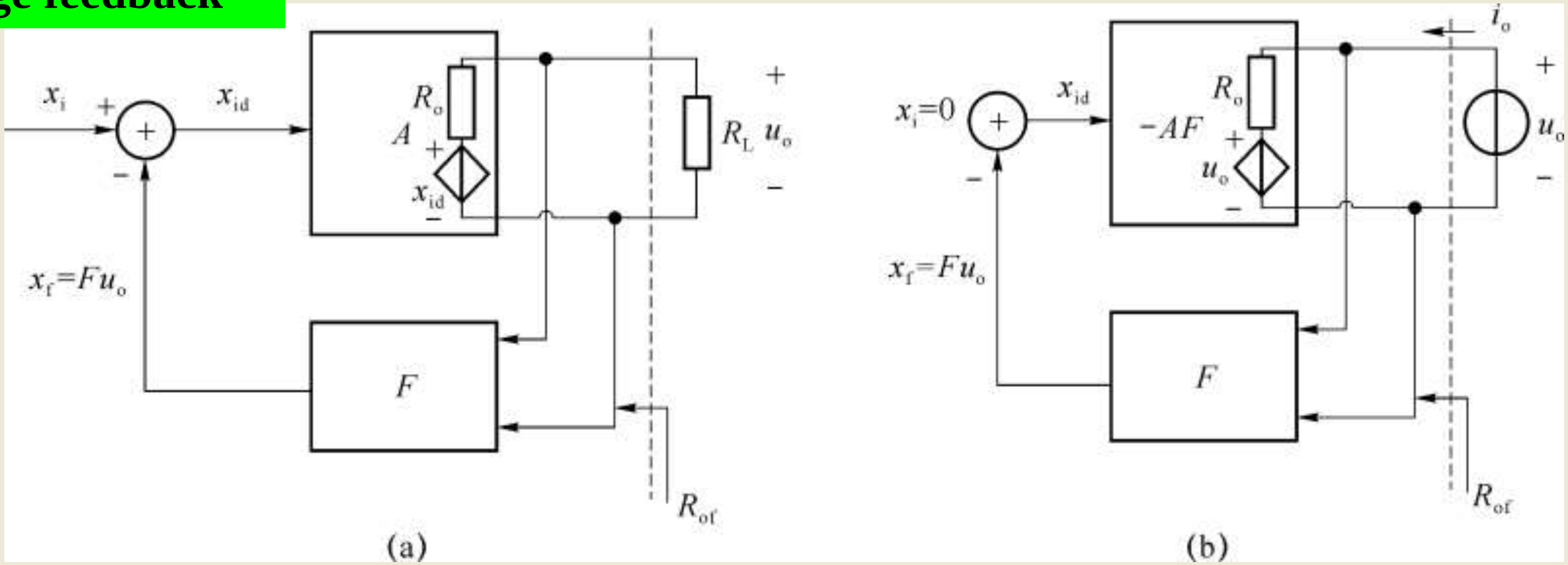
The closed-loop input resistance:

$$R_{if} = \frac{u_i}{i_i} = \frac{u_i}{i_{id} + i_f} = \frac{u_i}{i_{id} + AFi_{id}} = \frac{R_i}{1 + AF}$$

Negative ***parallel*** feedback ***reduces*** input resistance

6.3.2 Output Impedance with Feedback

Voltage feedback



$$R_{of} = \left.\frac{u_o}{i_o}\right|_{x_i=0}$$

$$i_o = \frac{u_o - A(0 - Fu_o)}{R_o} = \frac{(1+AF)u_o}{R_o}$$

$$R_{of} = \frac{u_o}{i_o} = \frac{R_o}{1+AF}$$

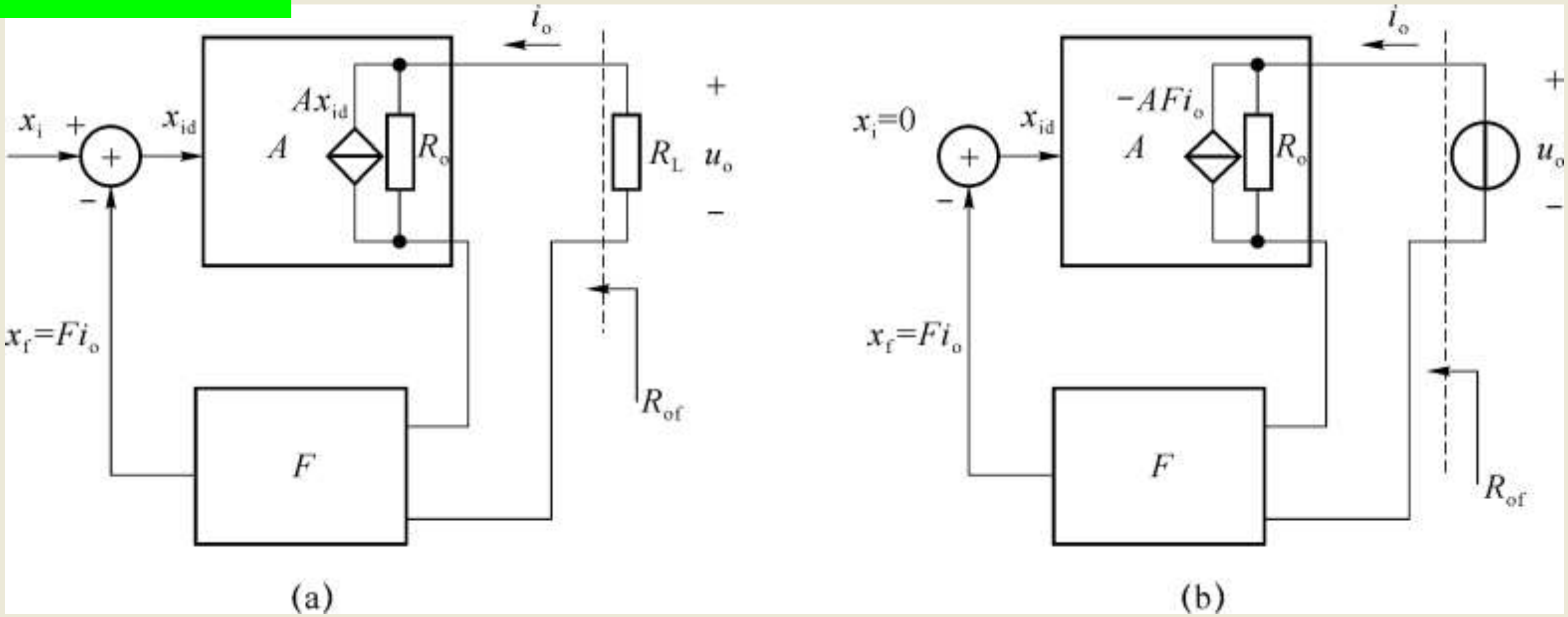
For ***strong negative feedback*** with $(1+AF) \to \infty$

$R_{of} \to 0$

Negative ***voltage*** feedback ***reduces*** the output resistance.

6.3.2 Output Impedance with Feedback

Current feedback



$$i_o = \frac{u_o}{R_o} + A(0 - Fi_o)$$

$$R_{of} = \frac{u_o}{i_o} = (1 + AF)R_o$$

For ***strong negative feedback*** with $(1+AF) \to \infty$

$R_{of} \to \infty$

Negative ***current*** feedback ***increases*** the output resistance.

6.3 Effect of Negative Feedback

when $AF >> 1$

- ***Gain***
  - Reduced gain, but improve gain stability $A_f = \dfrac{A}{1+AF}$ $\quad\quad A_f \approx \dfrac{1}{F}$
- ***Input impedance***
  - **- *series*: increase input impedance $R_{if} = (1+AF)R_i$ $\quad\quad R_{if} = \infty$
  - **- *parallel*: decrease input impedance $R_{if} = \dfrac{R_i}{1+AF}$ $\quad\quad R_{if} = 0$
- ***Output impedance***
  - *voltage*-**: decrease output impedance $R_{of} = \dfrac{R_o}{(1+AF)}$ $\quad\quad R_{of} = 0$
  - *current*-**: increase output impedance $R_{of} = (1+AF)R_o$ $\quad\quad R_{of} = \infty$
- ***Extends bandwidth*** $B_f = (1+AF)B$
- ***Reduce non-linear distortion***

6.4 Negative Feedback Amplifier Analysis

- ***General method***
  - Divide the close-loop amplifier into two parts: a basic open-loop amplifier and a feedback network.
  - For the open-loop amplifier, calculate A , R_i , R_o .
  - For the feedback network, calculate F .
  - Calculate A_f , A_{uf}, R_{if}, R_{of}

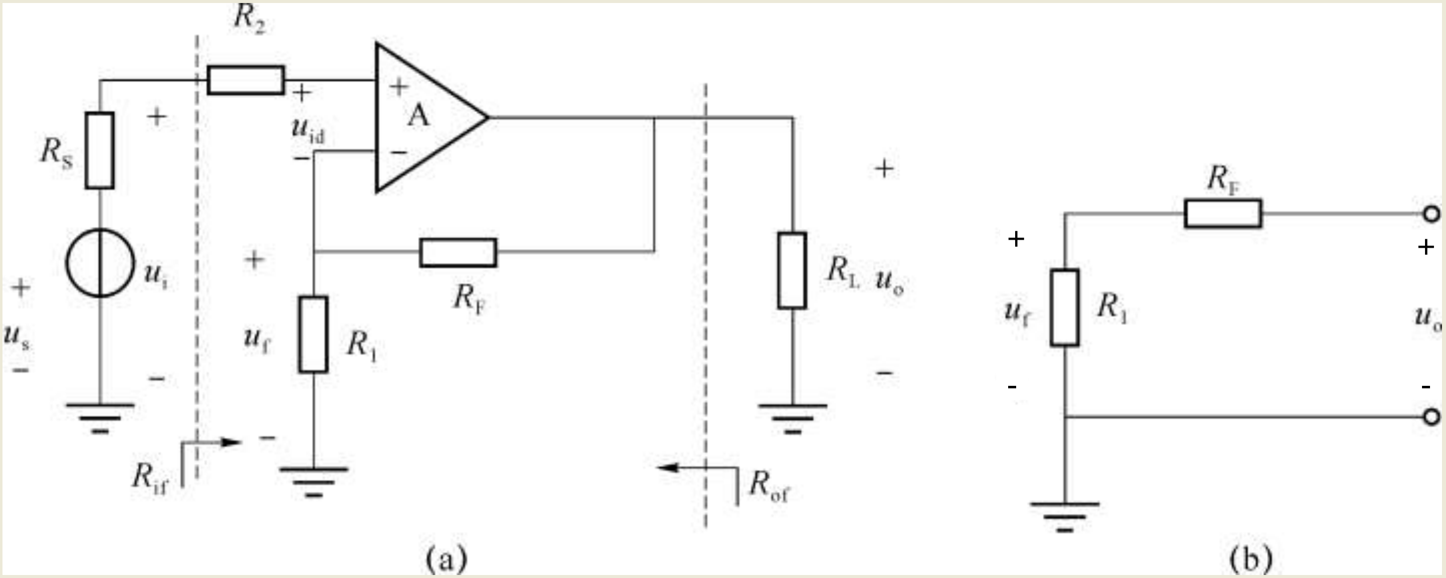
- ***Special case for Strong negative feedback***
  - Approximation method

when $AF >> 1$

Determine the feedback type (AC network)	→	Determine the feedback F	→	Determine the feedback gain $A_f \approx 1/F$	→	Determine other unknowns A_{uf}, R_{if}, R_{of}

Examples

Example 6.6: The AC network of a feedback amplifier is illustrated in Figure (a), identify the type of the negative feedback. Suppose it is a strong negative feedback, calculated the voltage gain, input resistance and output resistance of the amplifier denoted in the circuit.



It is a *voltage-series* negative feedback amplifier ⟶ Feedback network

$$A_f = \frac{x_o}{x_i} = \frac{u_o}{u_i} = A_{uf}$$

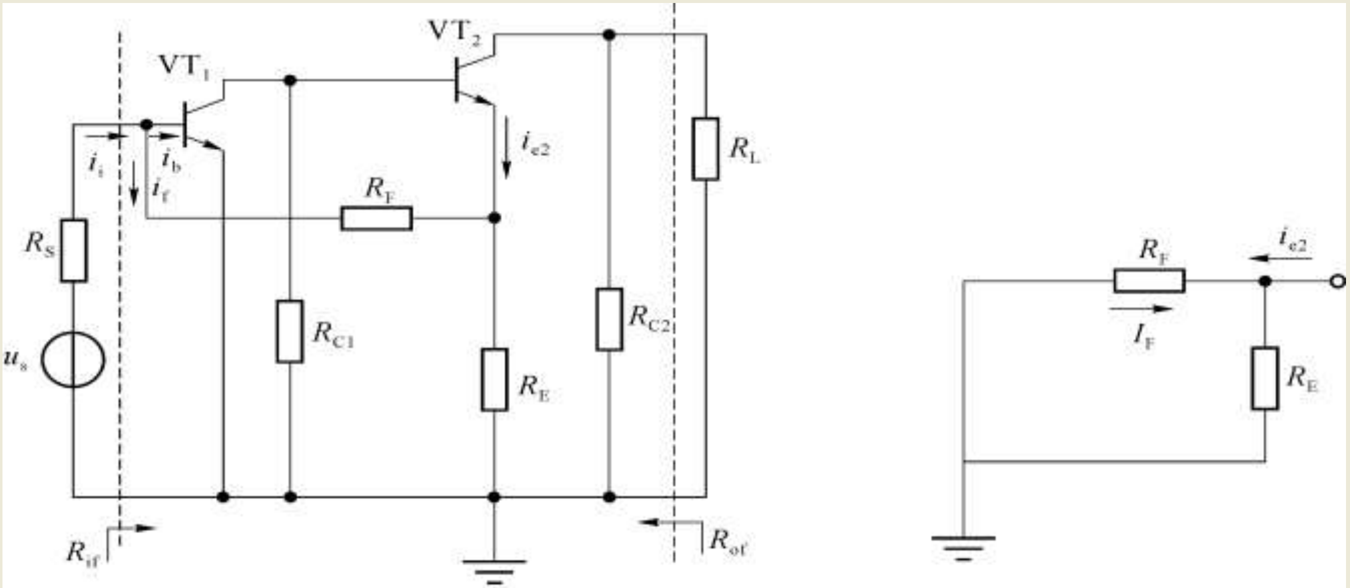
$$F = \frac{x_f}{x_o} = \frac{u_f}{u_o} = \frac{R_1}{R_1 + R_f}$$

$$A_f \approx \frac{1}{F} = 1 + \frac{R_f}{R_1} \qquad A_{uf} \approx 1 + \frac{R_f}{R_1}$$

$$R_{if} \approx \infty \qquad R_{of} \approx 0$$

Examples

Example 6.7: **The AC network of a feedback amplifier is illustrated in Figure (a), identify the type of the negative feedback. Suppose it is a strong negative feedback, calculated the voltage gain, input resistance and output resistance of the amplifier denoted in the circuit.**



(a) (b)

It is a *current-parallel* negative feedback amplifier ⟶ Feedback network

$$A_f = \frac{x_o}{x_i} = \frac{i_{e2}}{i_i} \approx \frac{i_{c2}}{i_i} \approx \frac{1}{F}$$

$$F = \frac{x_f}{x_o} = \frac{i_f}{i_{e2}} = -\frac{R_E}{R_E + R_F}$$

$$A_{uf} = \frac{u_o}{u_s} = \frac{-i_{c2}\left(R_{C2} \parallel R_L\right)}{R_s i_i} = -\frac{\left(R_{C2} \parallel R_L\right)}{R_s} A_f = \frac{\left(R_{C2} \parallel R_L\right)}{R_s}\left(1+\frac{R_F}{R_E}\right)$$

$$A_f \approx \frac{1}{F} = -\left(1+\frac{R_F}{R_E}\right)$$

$$R_{if} \approx 0 \qquad R_{of} \approx \infty$$

Summary

Feedback concepts

- Close-loop vs. Open-loop
- Find out feedback and determine the type of feedback
  - *DC feedback/AC feedback*
  - *Positive feedback/negative feedback*

Principles for negative feedback

- Determine the types of a negative feedback amplifier
  - *AC network*
  - *Voltage-series/voltage-parallel/current-series/current-parallel*
- Effects of negative feedback
  - *Gain/Input impedance/output impedance/……*
- Strong negative feedback
  - *Gain/input impedance/output impedance/……*

Approximation on quantitative analysis for strong negative feedback