

Feedback and stability

CM

Features

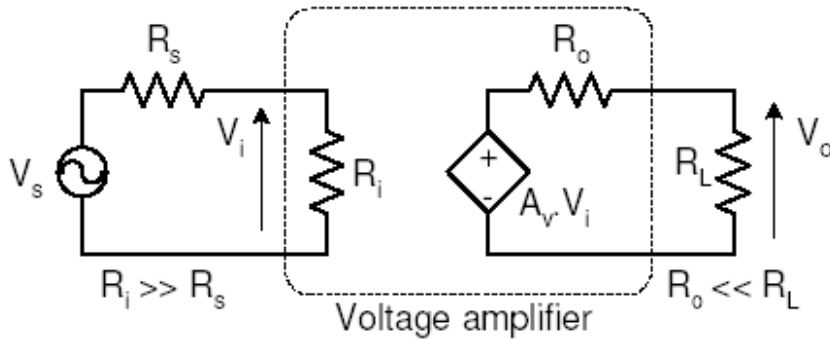
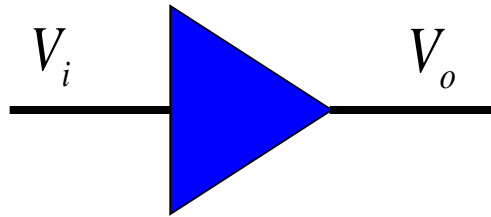
- Gain sensitivity
- Larger 3dB bandwidth
- SNR
- Distortion
- Impedance matching

Classification of amplifiers

- **Voltage amplifier**
- **Current amplifier**
- **Transconductance amplifier**
- **Transresistance amplifier**

Classification of amplifiers

1. Voltage amplifier



if $R_i \gg R_s$

then $V_i \approx V_s$

and if $R_o \ll R_L$

then,

$$V_o \approx A_v V_i \approx A_v V_s$$

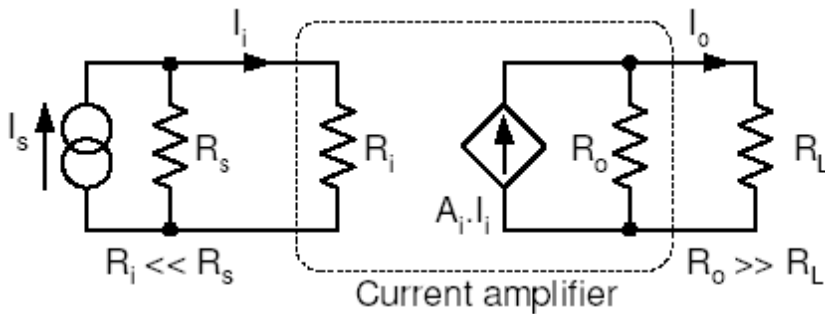
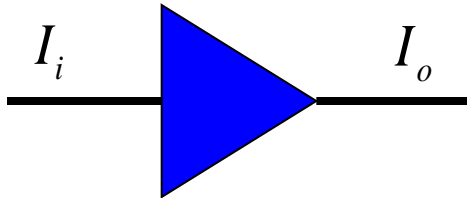
hence $A_v \equiv \frac{V_o}{V_i}$

with $R_L = \infty$

represent the open circuit voltage gain.

Classification of amplifiers

2. Current amplifier



if $R_i \ll R_s$

then $I_i \approx I_s$

and if $R_o \gg R_L$

then,

$$I_o \approx A_i I_i \approx A_i I_s$$

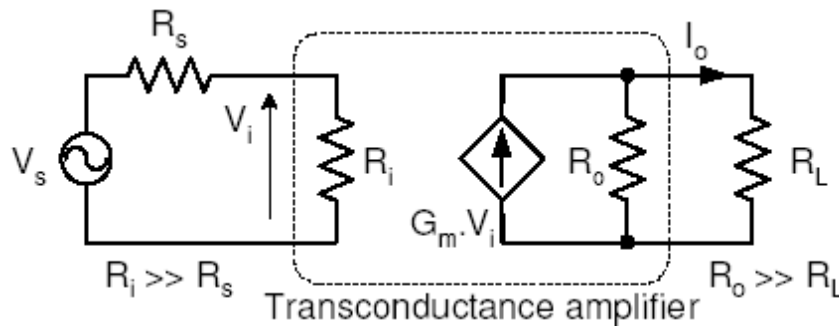
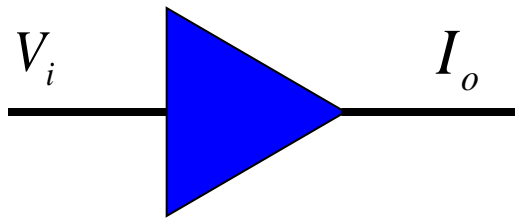
hence $A_i \equiv \frac{I_o}{I_i}$

with $R_L = 0$

represent the short circuit current gain.

Classification of amplifiers

3. Transconductance amplifier



if $R_i \gg R_s$

then $V_i \approx V_s$

and if $R_o \gg R_L$

then,

$$I_o \approx G_m V_i \approx G_m V_s$$

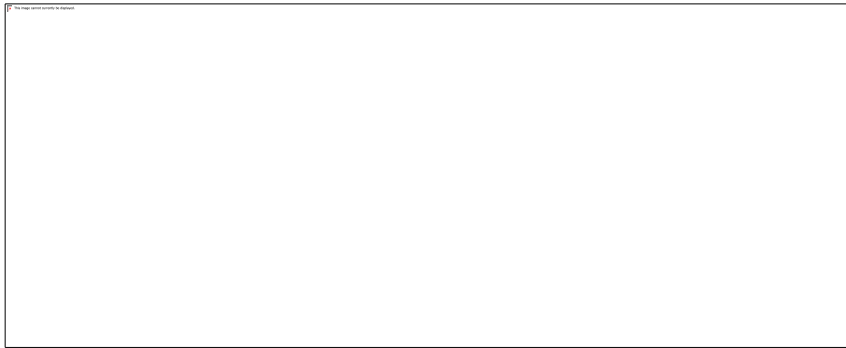
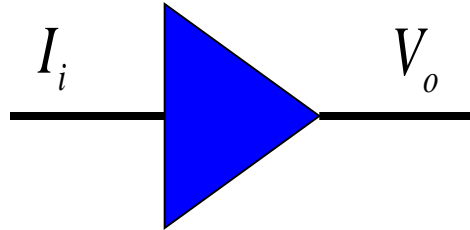
hence $G_m \equiv \frac{I_o}{V_i}$

with $R_L = 0$

represent the short circuit mutual or transfer conductance

Classification of amplifiers

4. Transresistance amplifier



if $R_i \ll R_s$

then $I_i \approx I_s$

and if $R_o \ll R_L$

then ,

$$V_o \approx R_m I_i \approx R_m i_s$$

hence $R_m \equiv \frac{V_o}{I_i}$

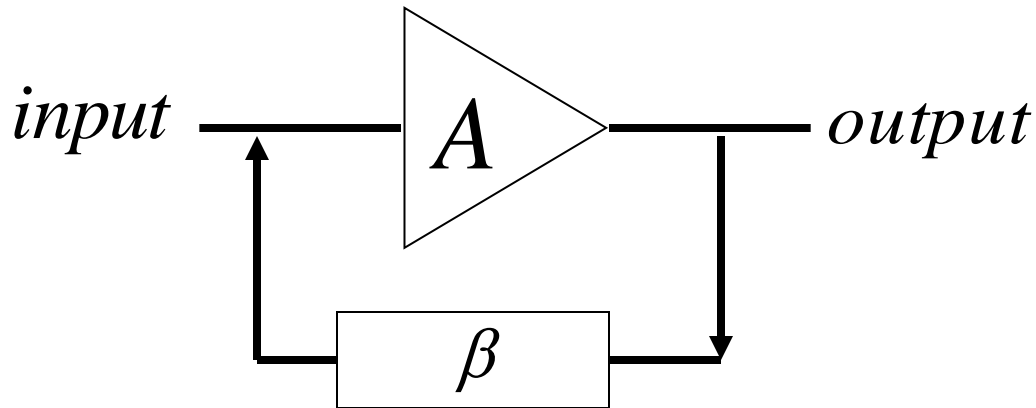
with $R_L = \infty$

represent the open circuit mutual or transfer resistance.

Types of feedback

What is feedback?

- **Feedback is a technique where a proportion of the output of a system (amplifier) is *fed back* and *recombined* with input.**

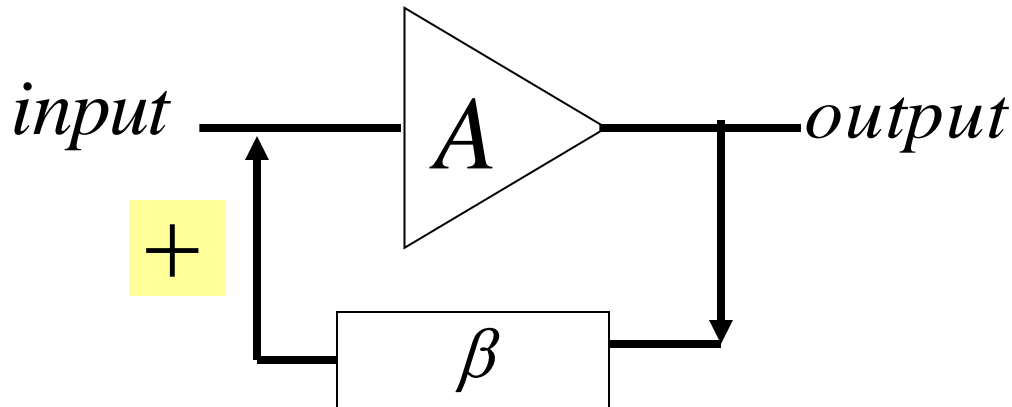


- There are two types of feedback amplifier.
 - *Positive feedback*
 - *Negative feedback*

Types of feedback

1. Positive Feedback

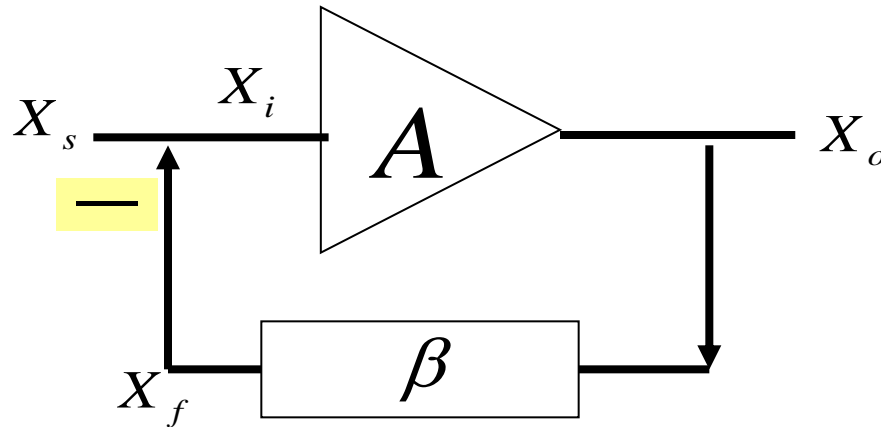
- Positive feedback is the process when the output is **added** to the input, amplified again, and this process continues.



- Example: In a PA system, you get feedback when you put the microphone in front of a speaker and the sound gets uncontrollably loud (you have probably heard this unpleasant effect).

Types of feedback

Negative Feedback Gain



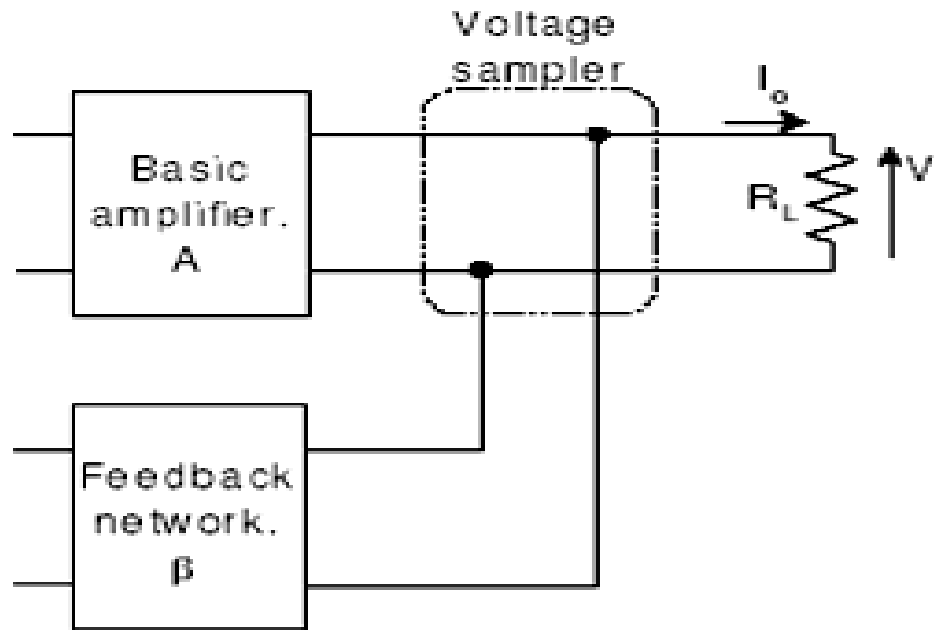
The gain with feedback (or closed-loop gain) A_f as follows:

$$X_o = A.X_i \quad X_i = X_s - X_f \quad X_f = \beta.X_o$$

$$A_f = \frac{X_o}{X_s} = \frac{A}{1 + \beta A}$$

The quantity βA is called the loop gain, and the quantity $(1 + \beta A)$ is called the amount of feedback.

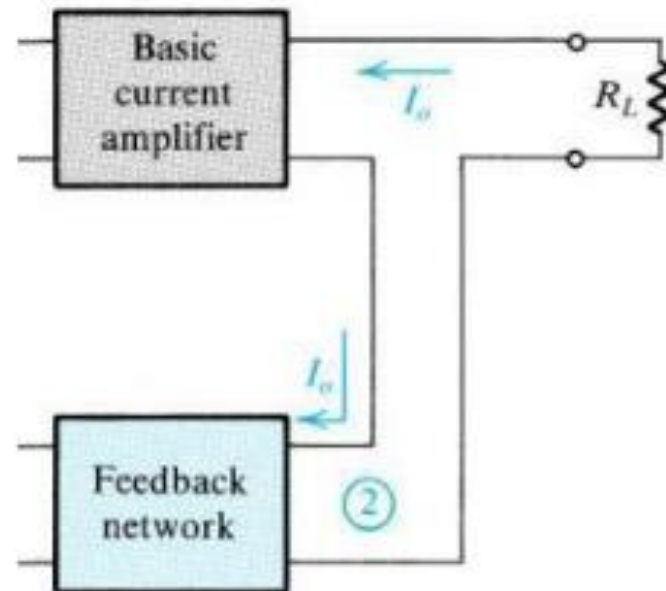
Sampling Network

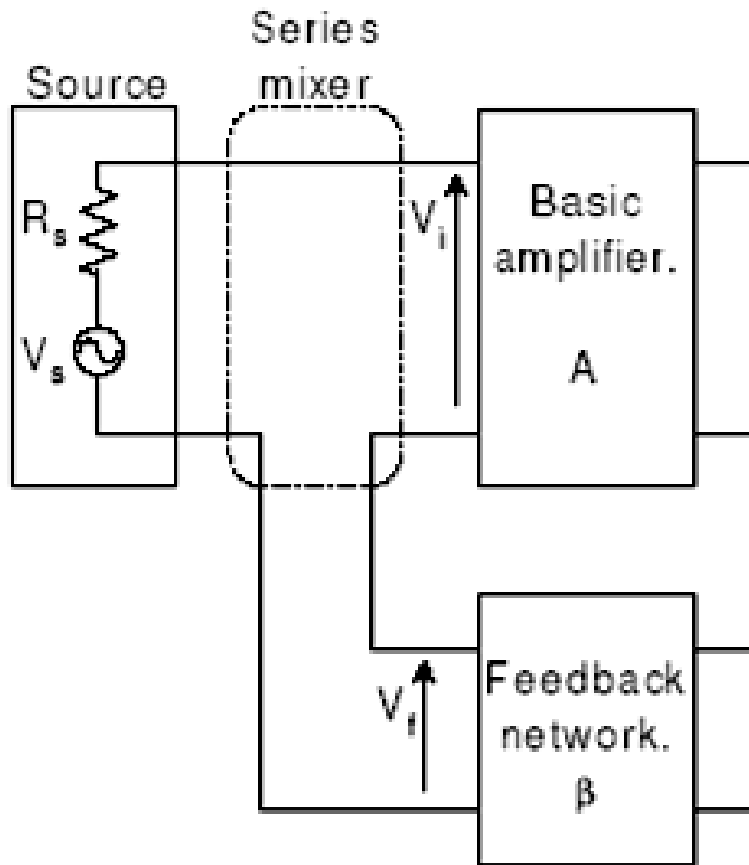


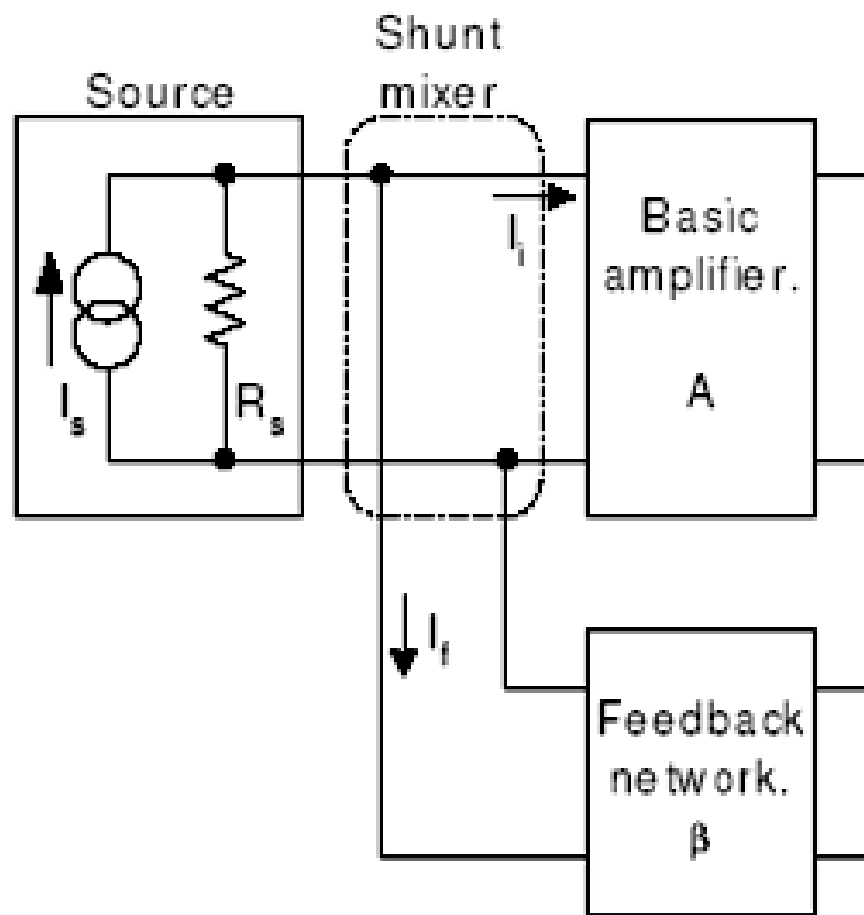
- The output **voltage** is sampled by connecting the feedback network in **shunt** across the output.
- Type of connection is referred to as *voltage or shunt or node sampling*.

Sampling Network

Current-Sampling

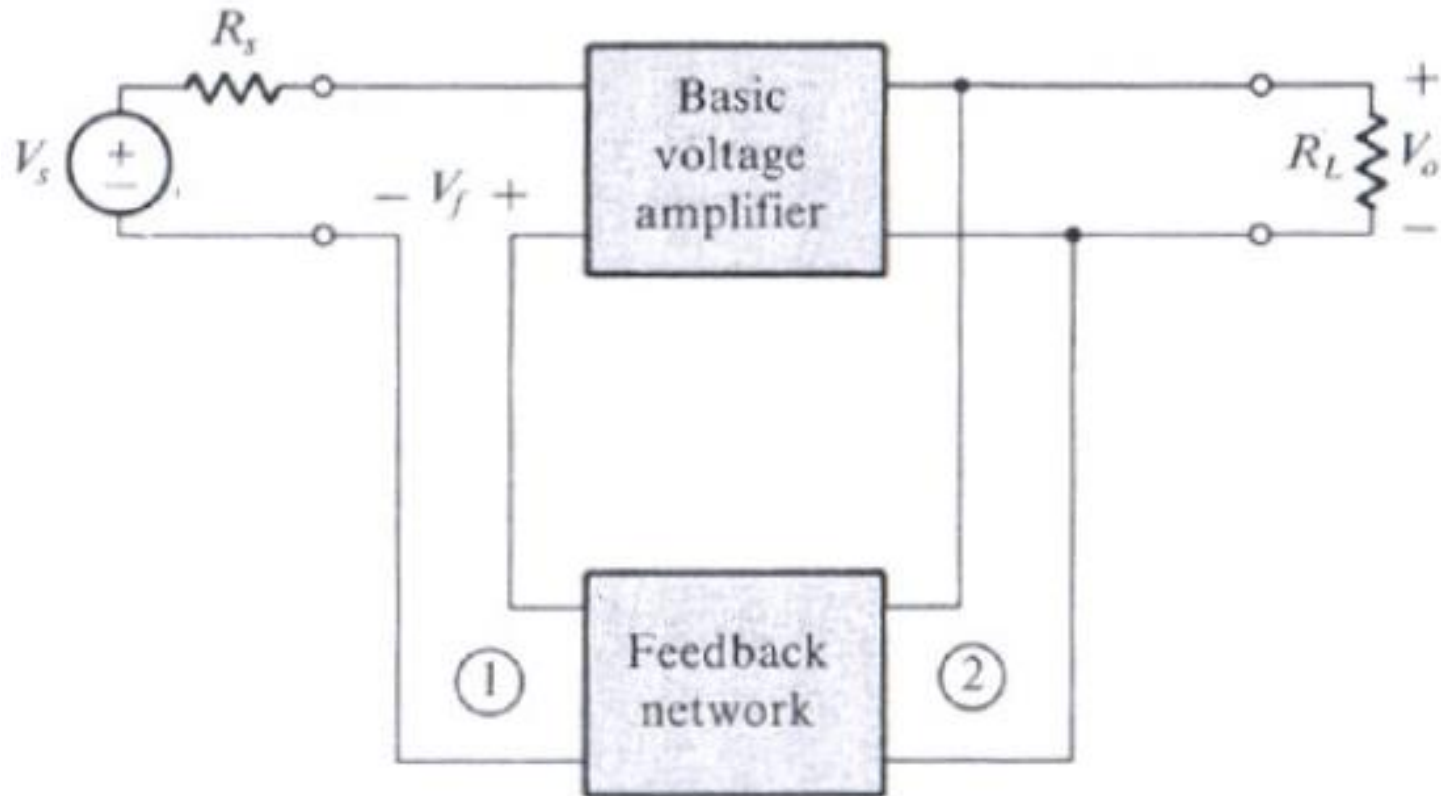






Feedback Topologies

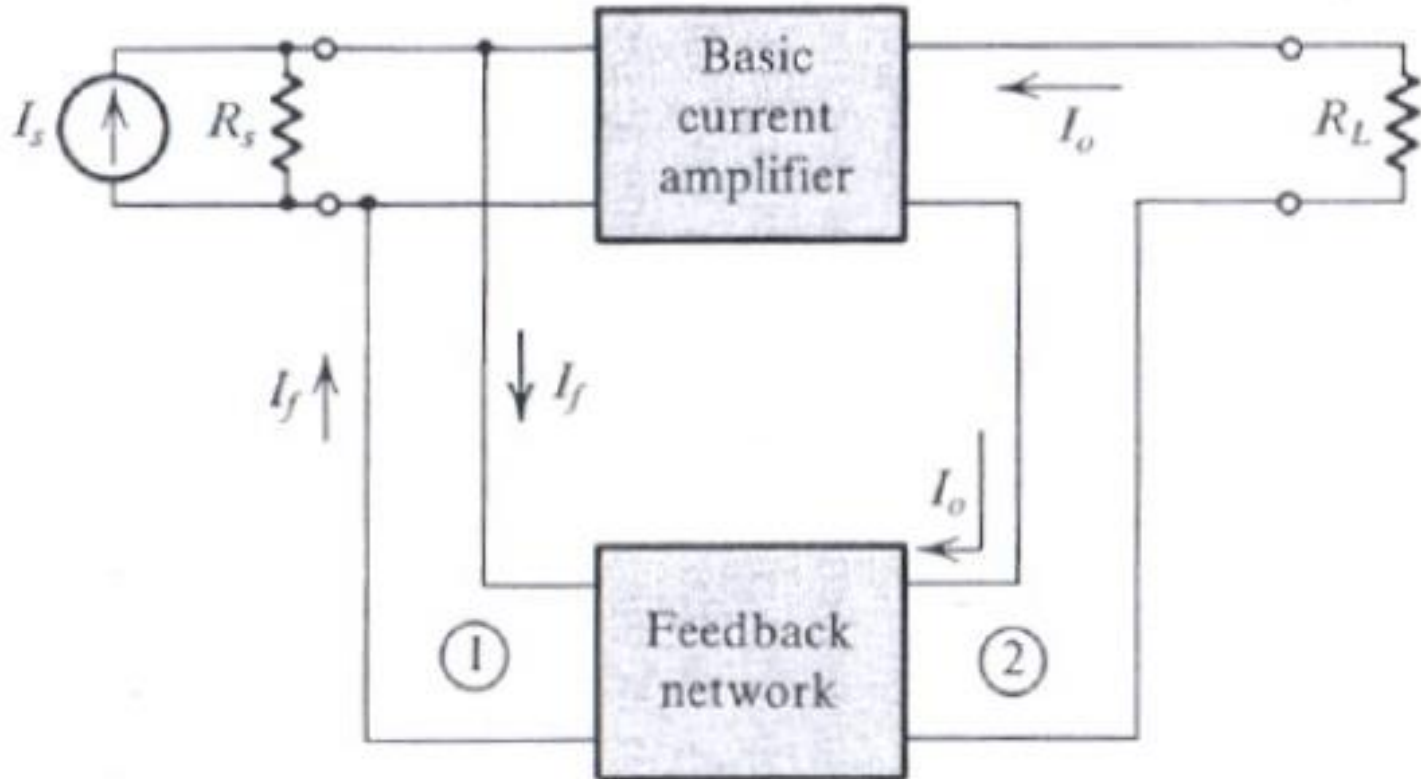
1. Series-shunt topology



Voltage-mixing voltage-sampling

Feedback Topologies

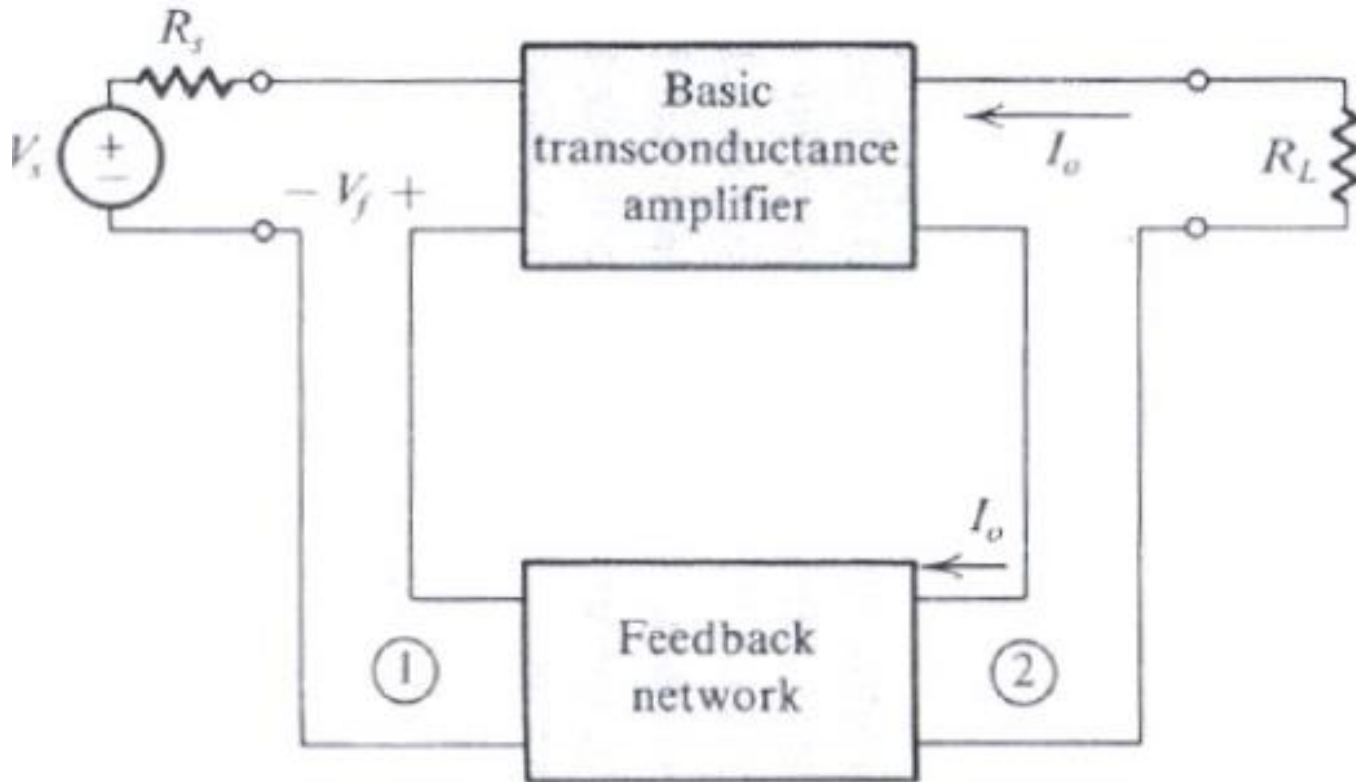
2. Shunt-series topology



Current-mixing current-sampling

Feedback Topologies

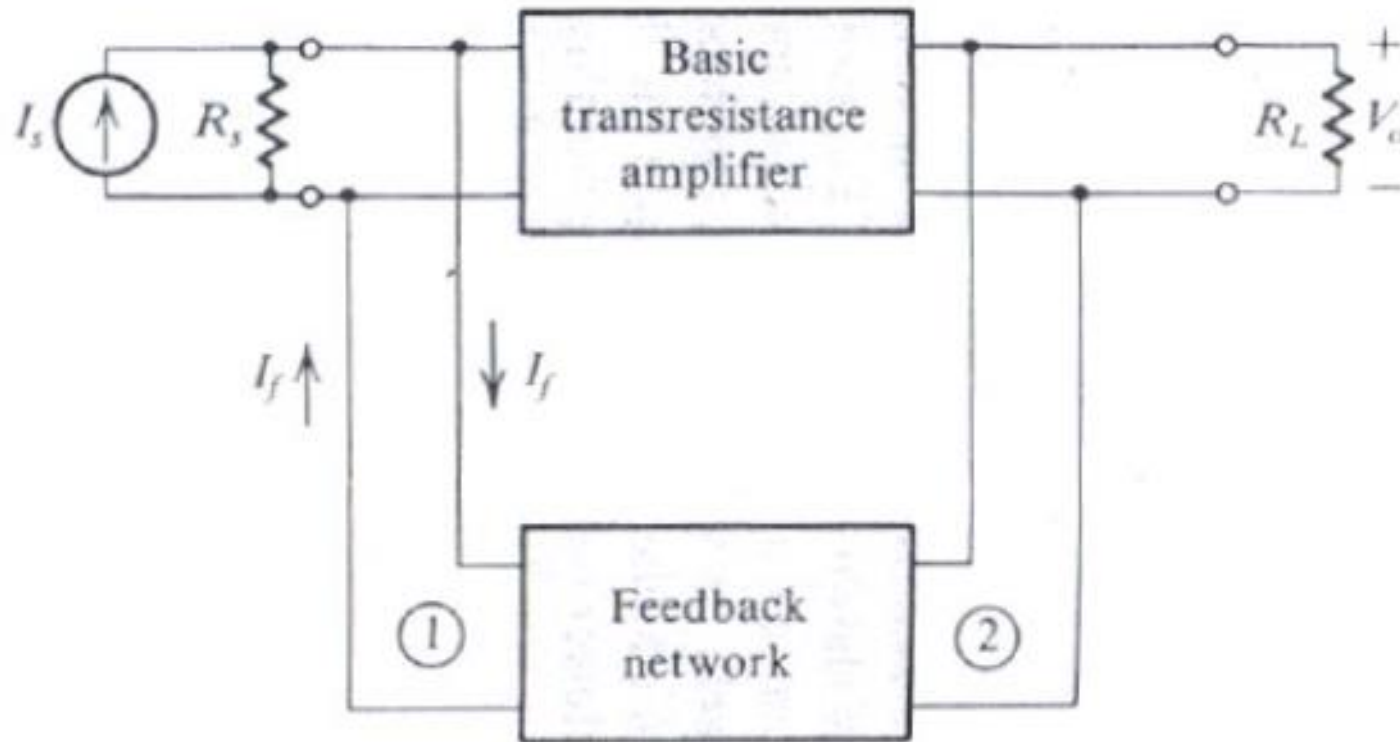
3. Series-series topology



Voltage-mixing current-sampling

Feedback Topologies

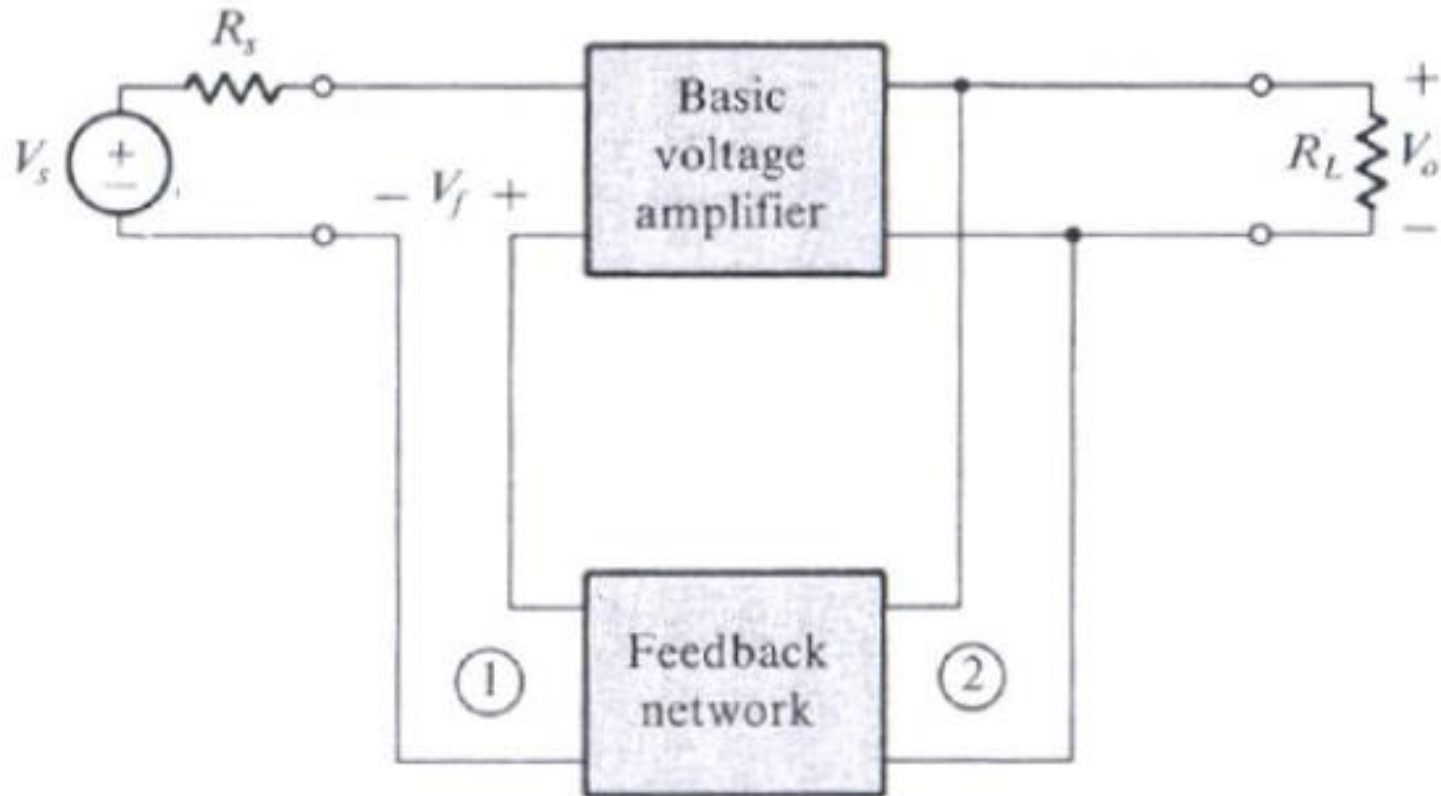
4. Shunt-shunt topology



Current-mixing voltage-sampling

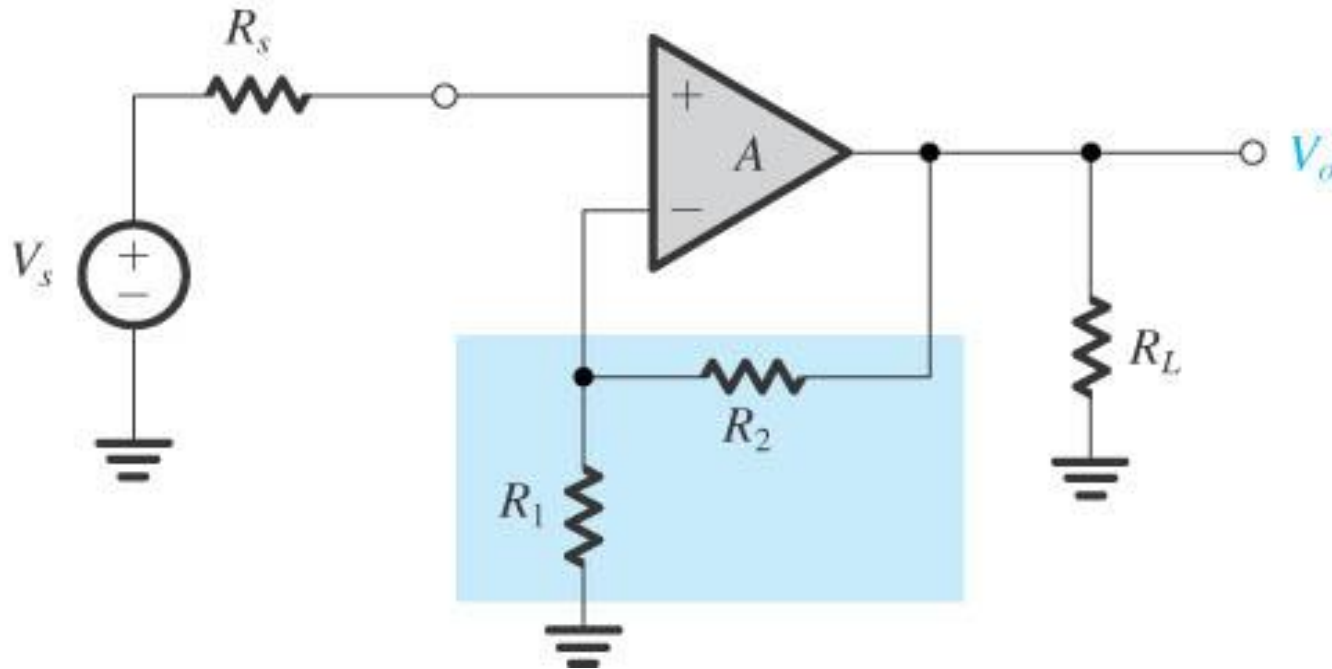
Feedback Topologies

1. Series-shunt topology



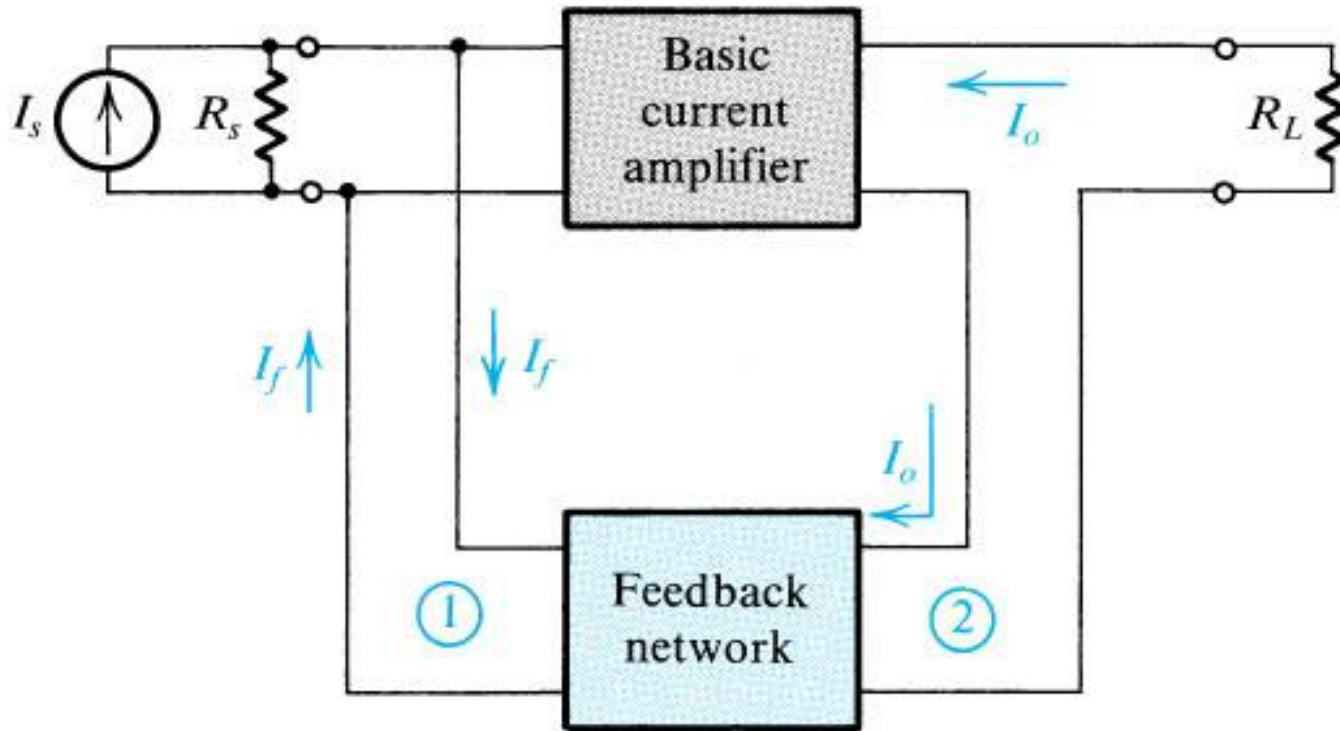
Voltage-mixing voltage-sampling

The Amplifier with Series-Shunt Feedback



voltage-mixing voltage-sampling (series-shunt) topology

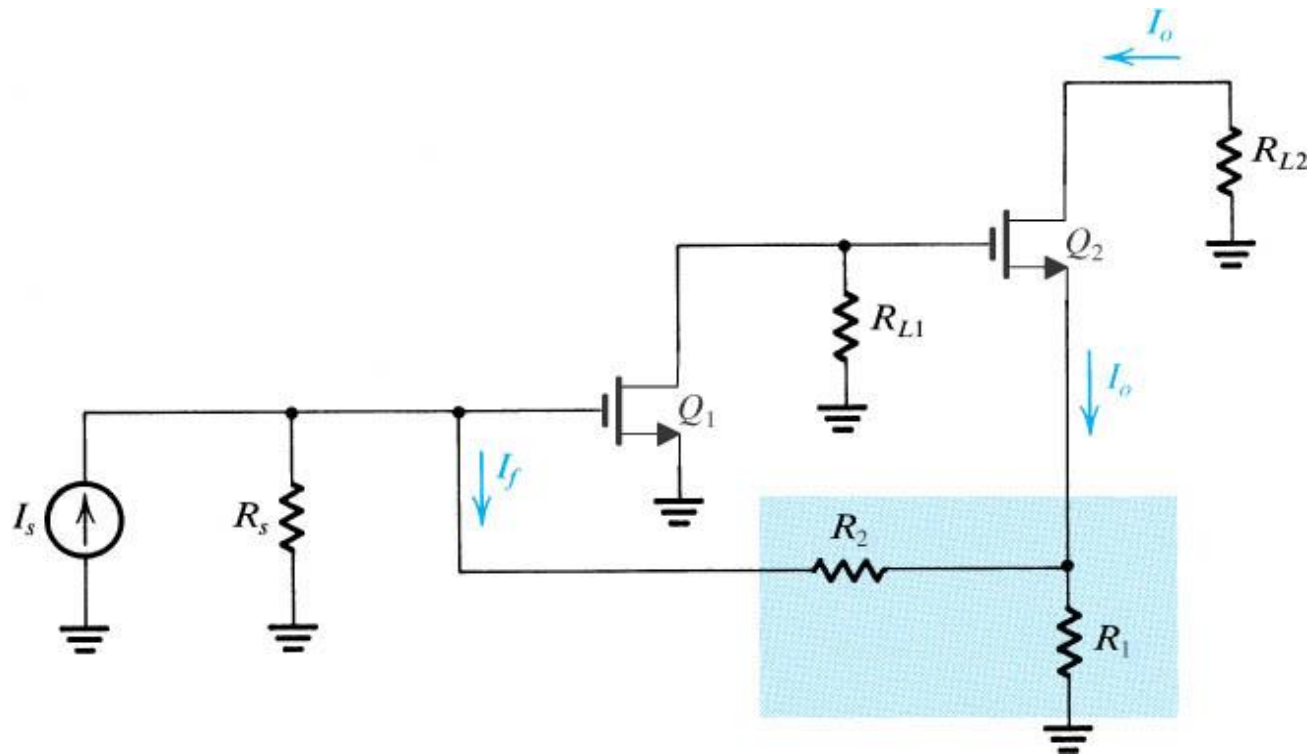
The Shunt-Series Feedback Topologies



(b)

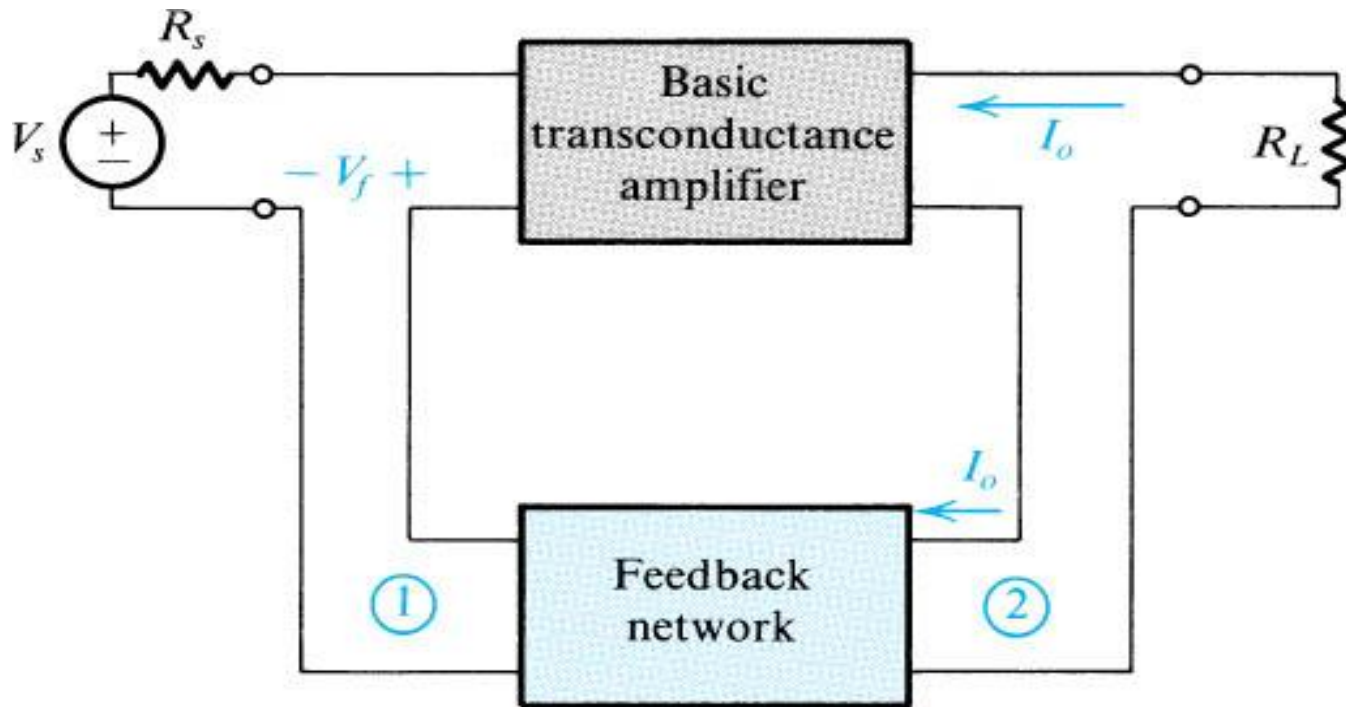
current-mixing current-sampling (shunt-series) topology

The Amplifier with Shunt-Series Feedback



current-mixing current-sampling (shunt-series) topology

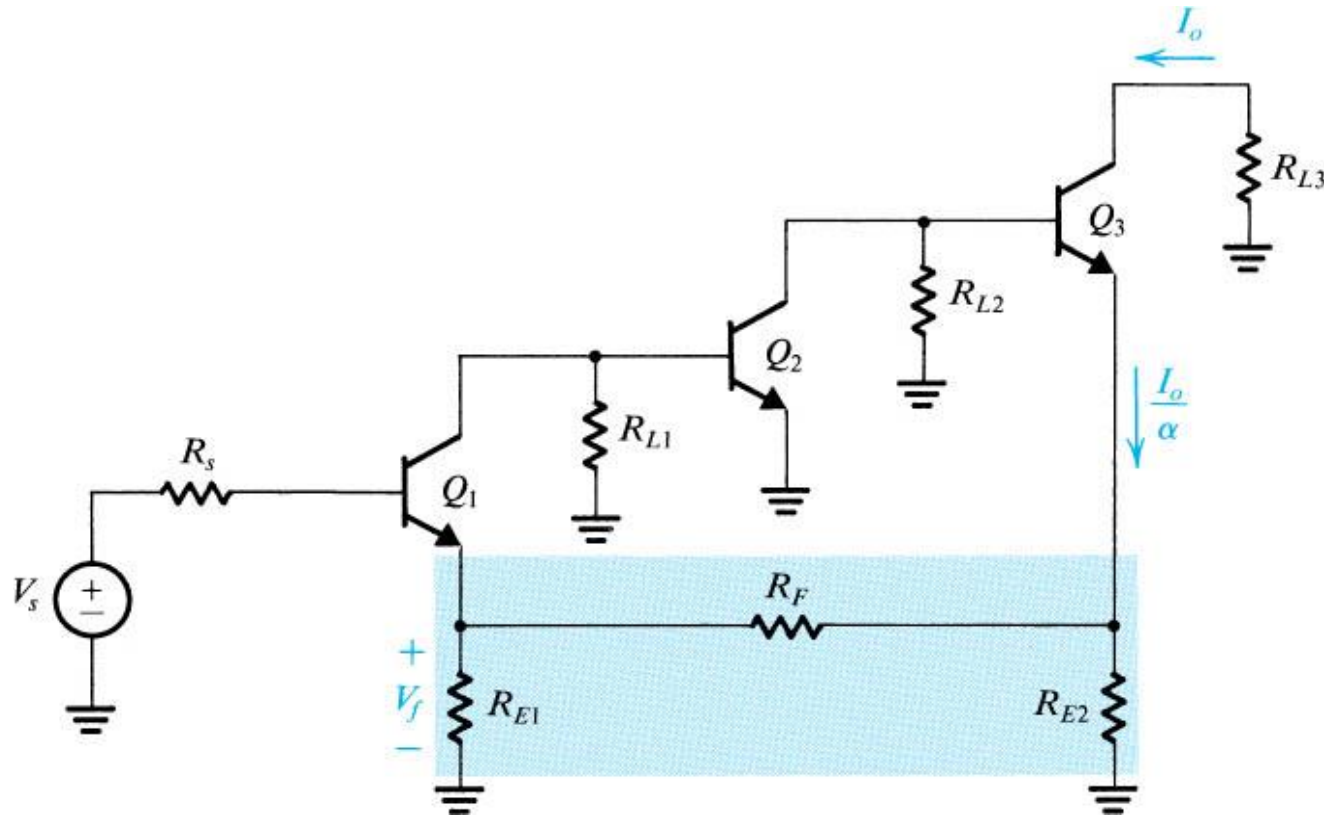
The Series-Series Feedback Topologies



(c)

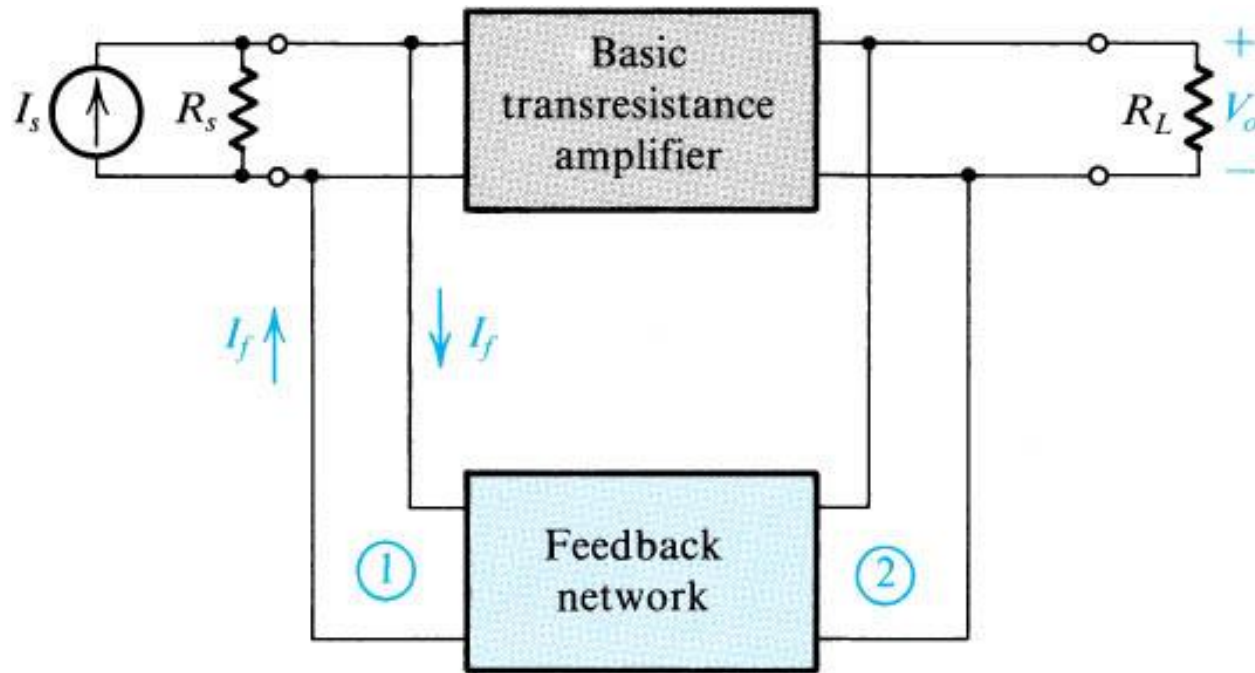
voltage-mixing current-sampling (series-series) topology

The Amplifier with Series-Series Feedback



voltage-mixing current-sampling (series-series) topology

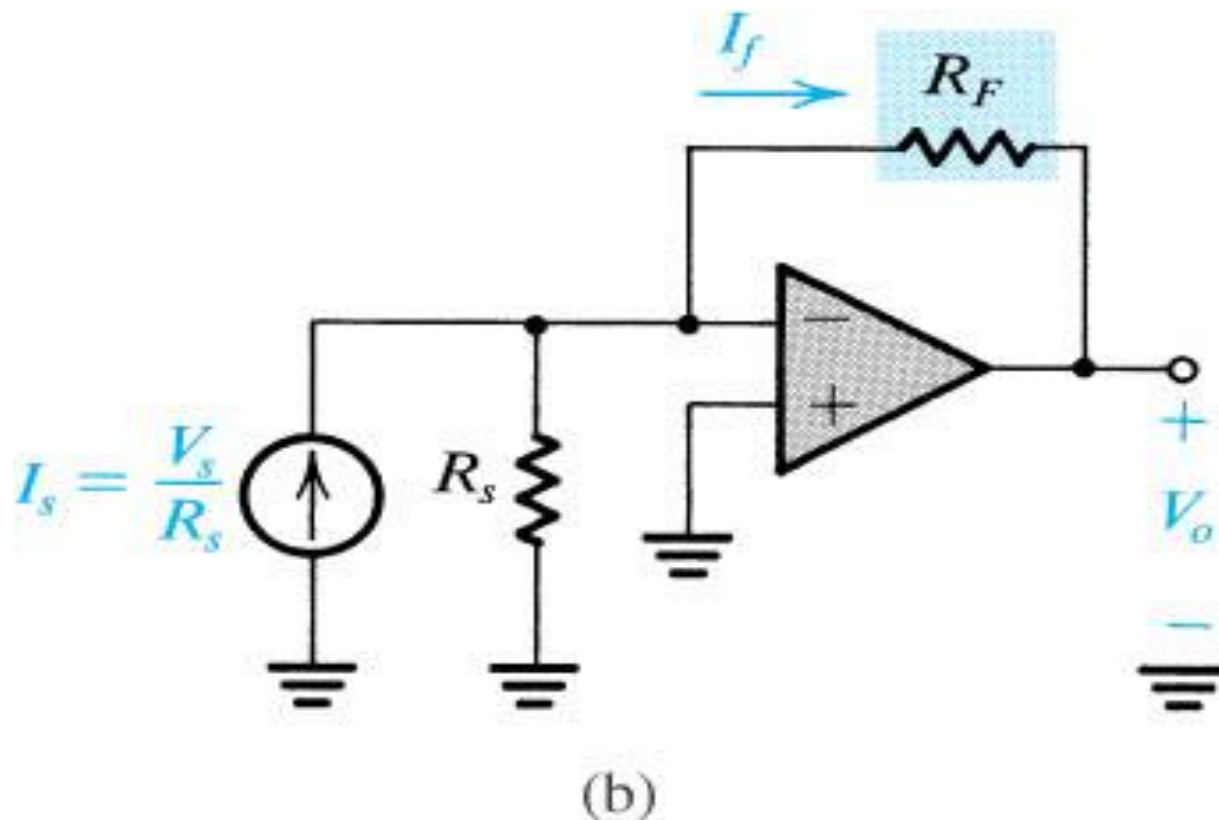
The Shunt-Shunt Feedback Topologies



(d)

current-mixing voltage-sampling (shunt-shunt) topology

The OP Amplifier with Shunt-Shunt Feedback

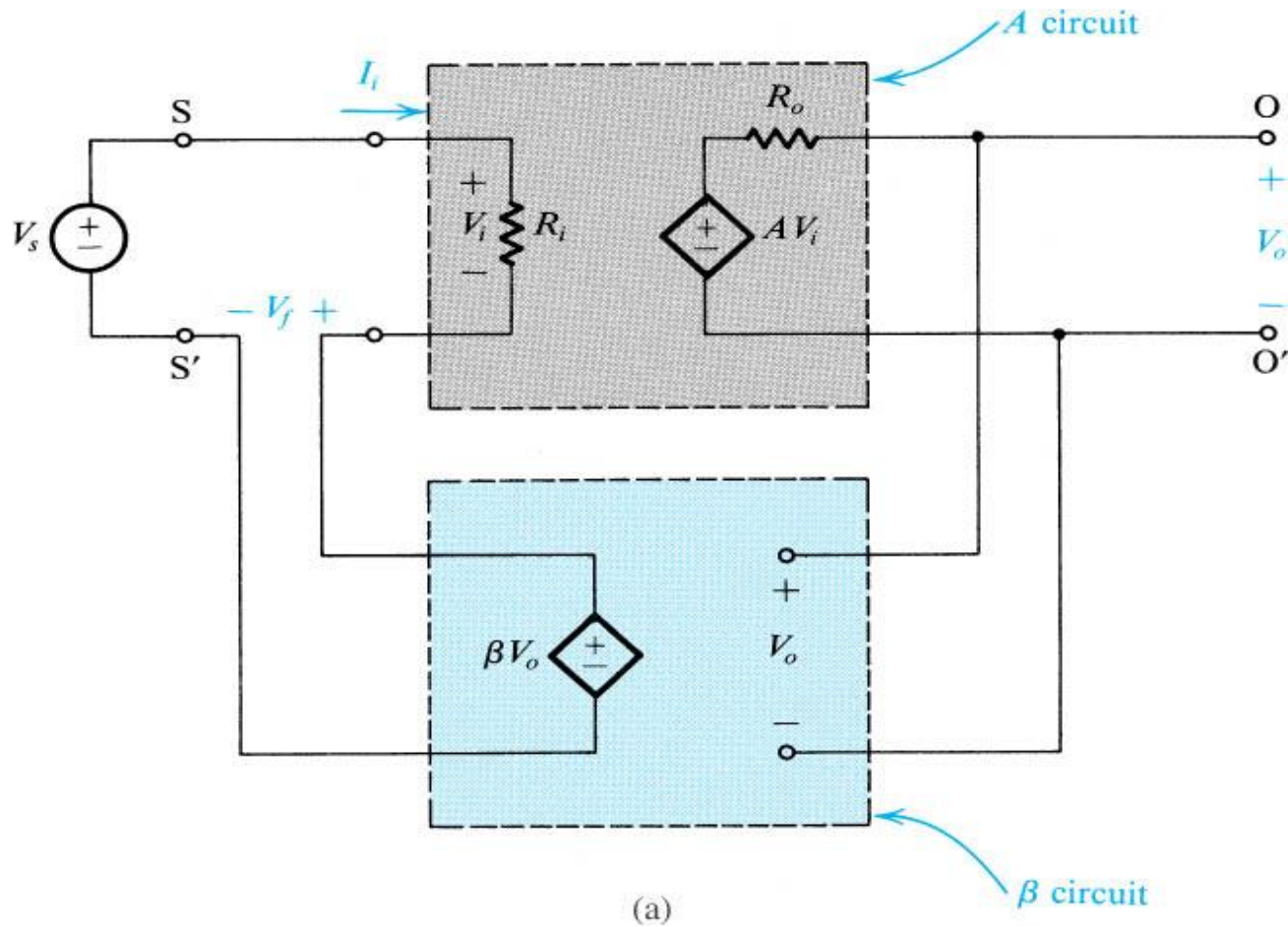


current-mixing voltage-sampling (shunt-shunt) topology

The Series-Shunt Feedback Amplifier

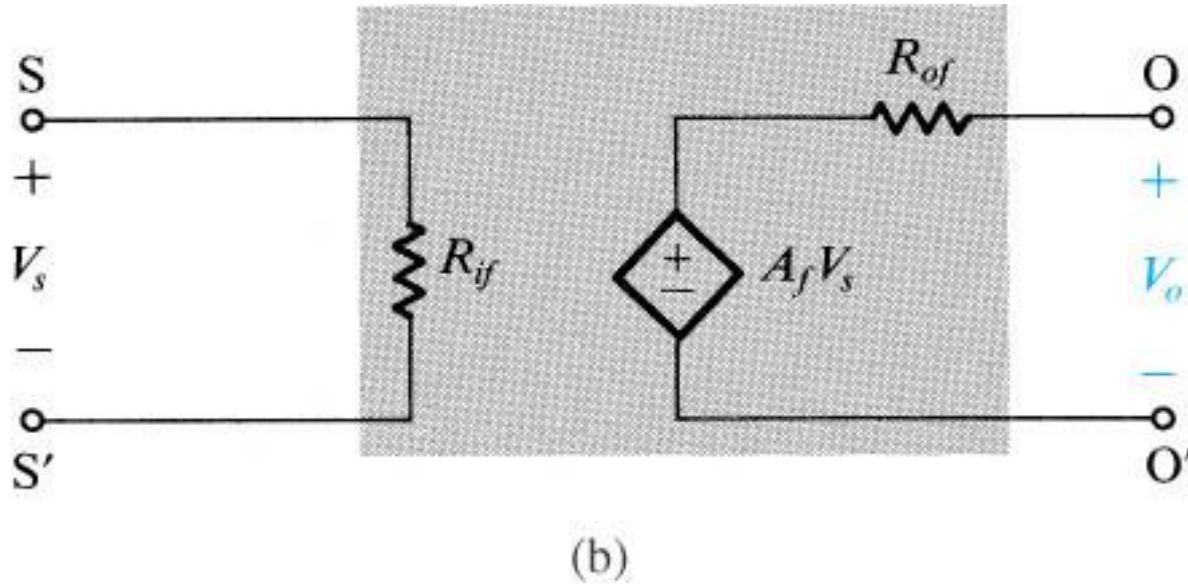
- The ideal situation
- The practical situation
- summary

The Ideal Situation



- A unilateral open-loop amplifier (A circuit).
- An ideal voltage mixing voltage sampling feedback network (β circuit).
- Assumption that the source and load resistance have been included inside the A circuit.

The Ideal Situation



Equivalent circuit.

R_{if} and R_{of} denote the input and output resistance with feedback.

Input and Output Resistance with Feedback

- Input resistance

$$R_{if} = R_i(1 + A\beta)$$

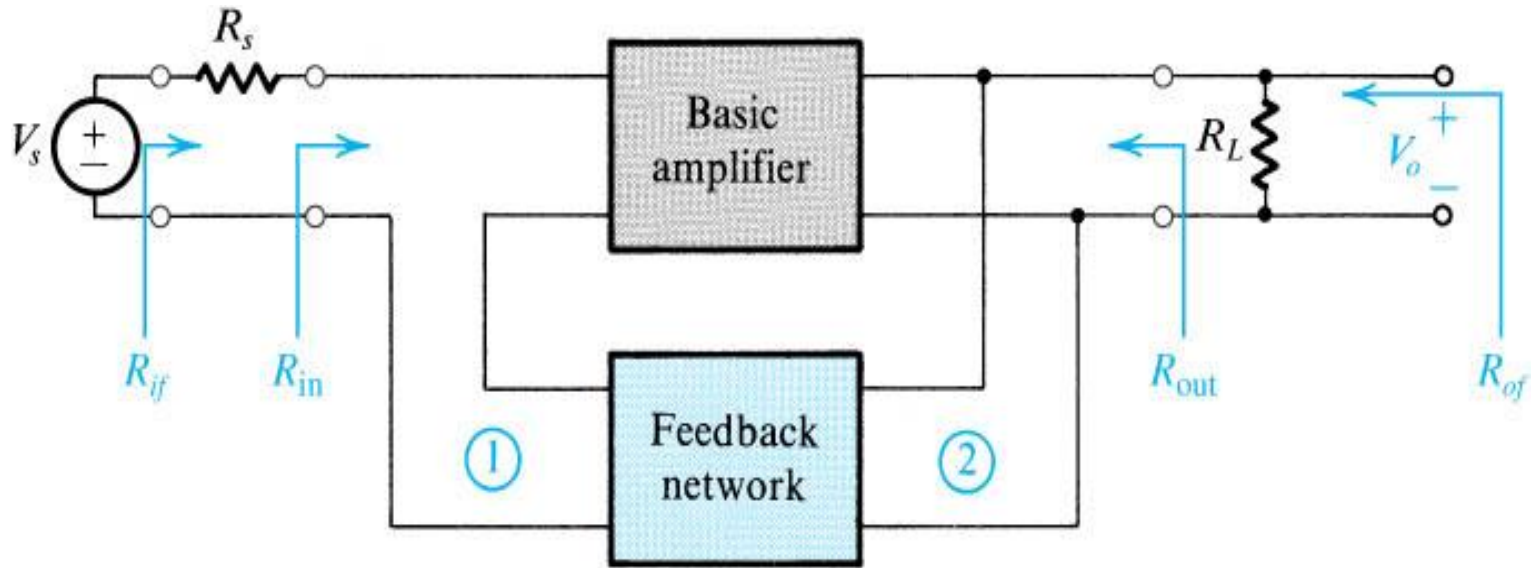
In this case, the negative feedback increases the input resistance by a factor equal to the amount of feedback.

- Output resistance

$$R_{of} = \frac{R_o}{1 + A\beta}$$

In this case, the negative feedback reduces the output resistance by a factor equal to the amount of feedback.

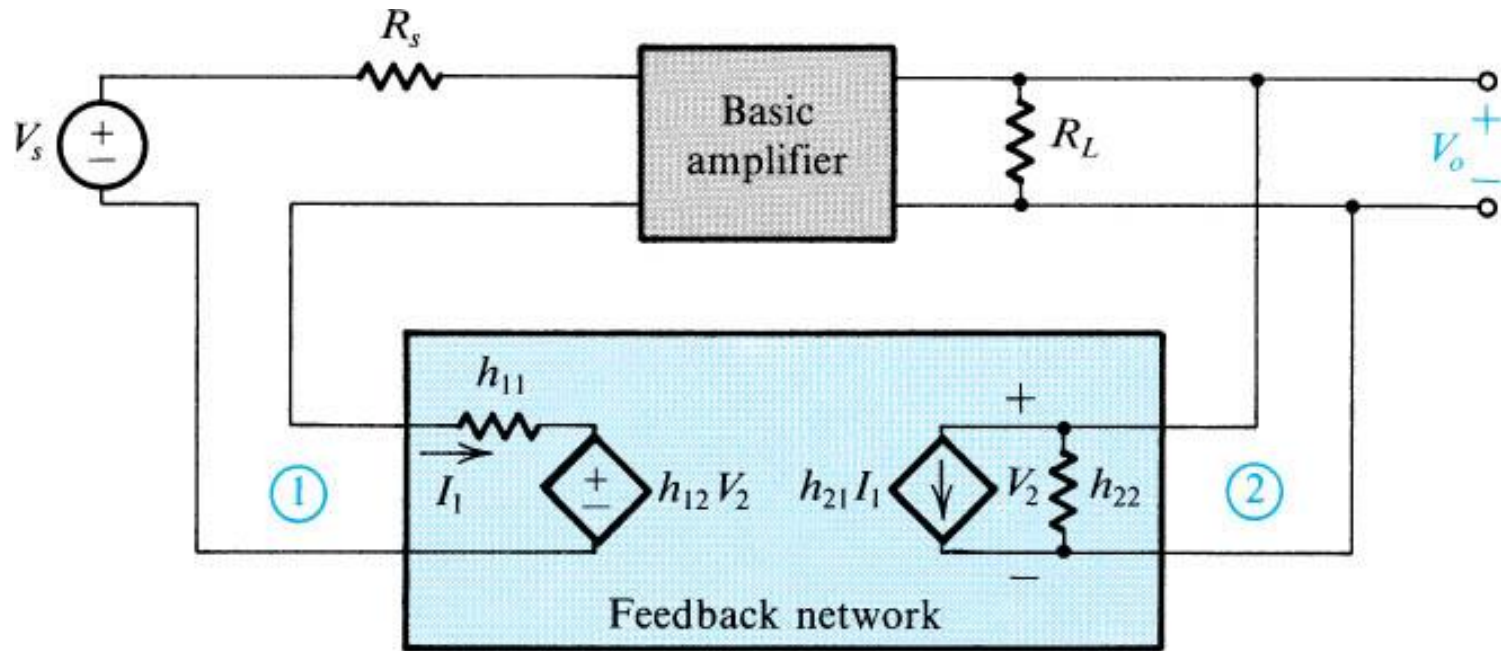
The Practical Situation



(a)

- Block diagram of a practical series–shunt feedback amplifier.
- Feedback network is not ideal and load the basic amplifier thus affect the values of gain, input resistance and output resistance.

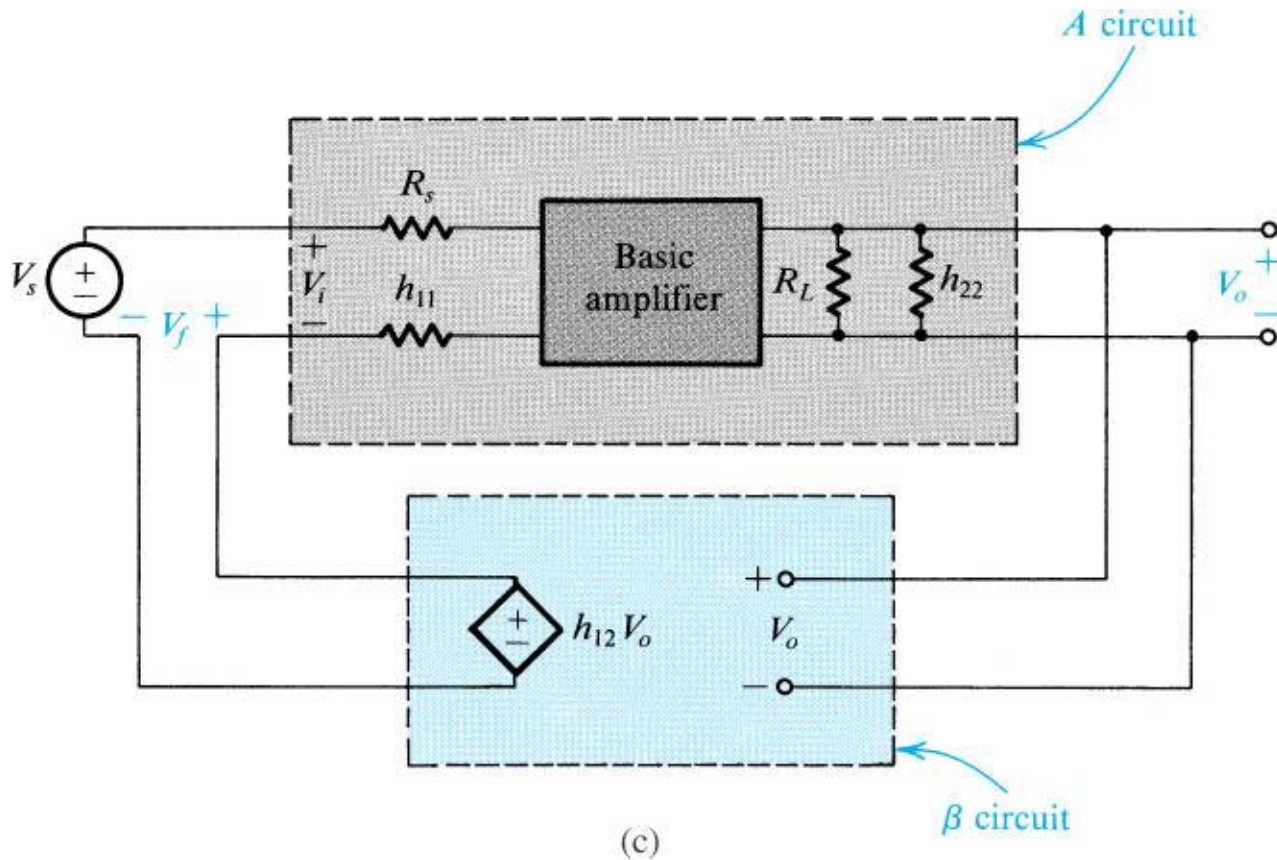
The Practical Situation



(b)

The circuit in (a) with the feedback network represented by its h parameters.

The Practical Situation



The circuit in (b) with h_{21} neglected.

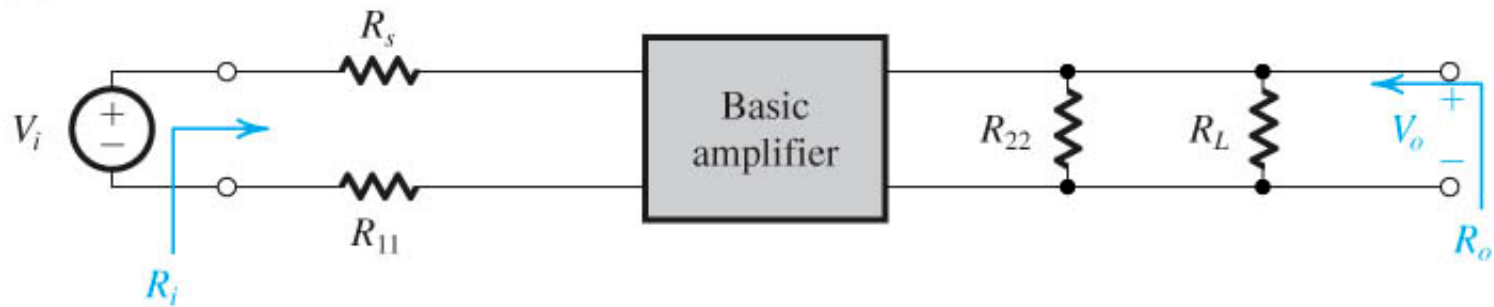
The Practical Situation

- The load effect of the feedback network on the basic amplifier is represented by the components h_{11} and h_{22} .
- The loading effect is found by looking into the appropriate port of the feedback network while the port is open-circuit or short-circuit so as to destroy the feedback.

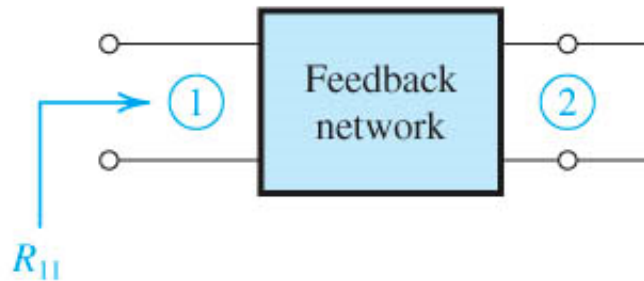
- If the connection is a shunt one, short-circuit the port.
- If the connection is a series one, open-circuit the port.
- Determine the β .

$$\beta = h_{12} \equiv \left. \frac{V_1}{V_2} \right|_{I_1=0}$$

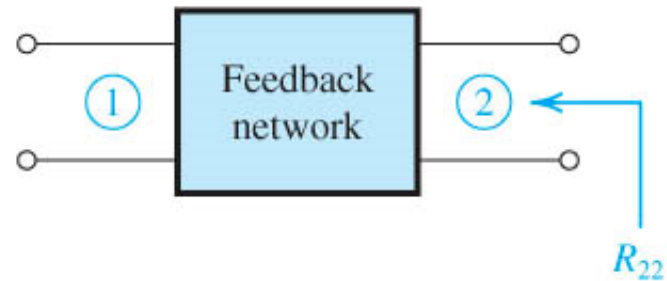
(a) The A circuit is



where R_{11} is obtained from



and R_{22} is obtained from



and the gain A is defined $A \equiv \frac{V_o}{V_i}$

(b) β is obtained from



$$\beta \equiv \left. \frac{V_f}{V_o} \right|_{I_1 = 0}$$

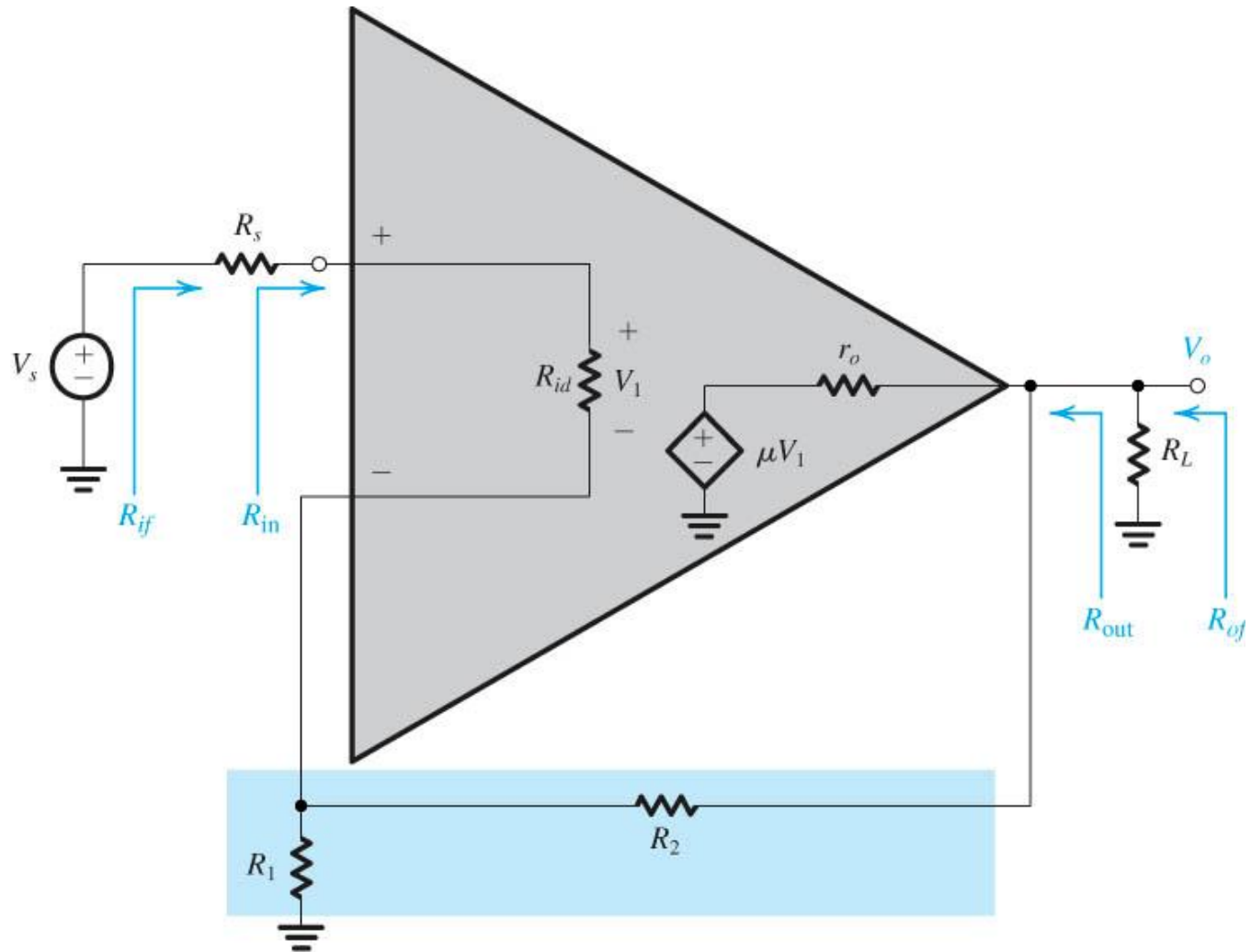
Summary

- R_i and R_o are the input and output resistances, respectively, of the A circuit.
- R_{if} and R_{of} are the input and output resistances, respectively, of the feedback amplifier, including R_s and R_L .
- The actual input and output resistances exclude R_s and R_L .

$$R_{if} = R_{in} + R_s$$

$$R_{of} = R_{out} // R_L$$

Example of Series-Shunt Feedback Amplifier

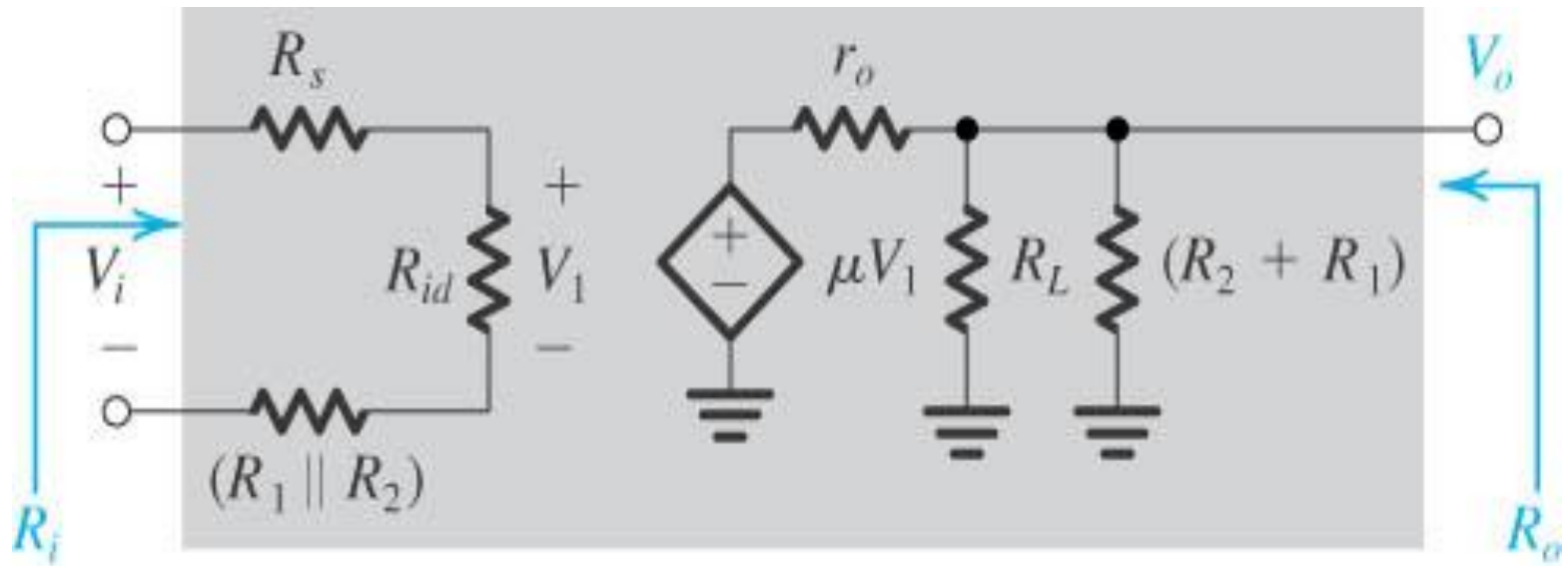


(a)

Example of Series-Shunt Feedback Amplifier

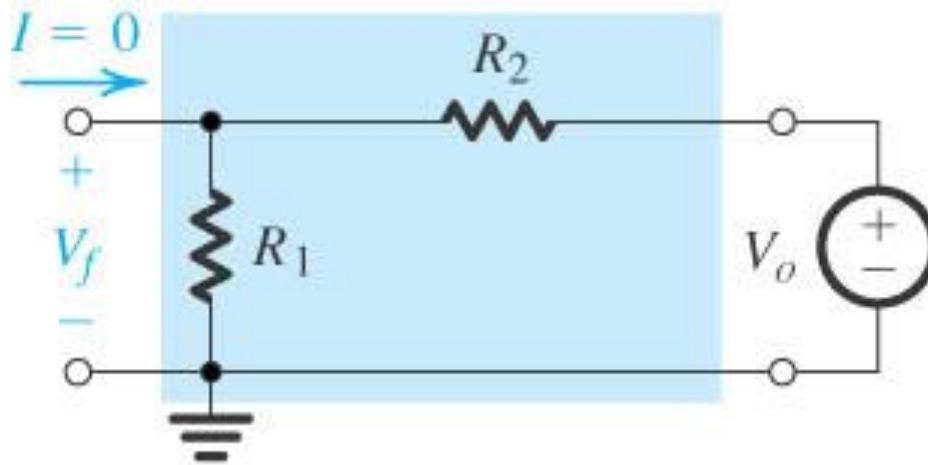
- Op amplifier connected in noninverting configuration with the open-loop gain μ , R_{id} and r_o
- Find expression for A , β , the closed-loop gain V_o/V_i , the input resistance R_{in} and the output resistance R_{out}
- Find numerical values

Example of Series-Shunt Feedback Amplifier



(b)

Example of Series-Shunt Feedback Amplifier



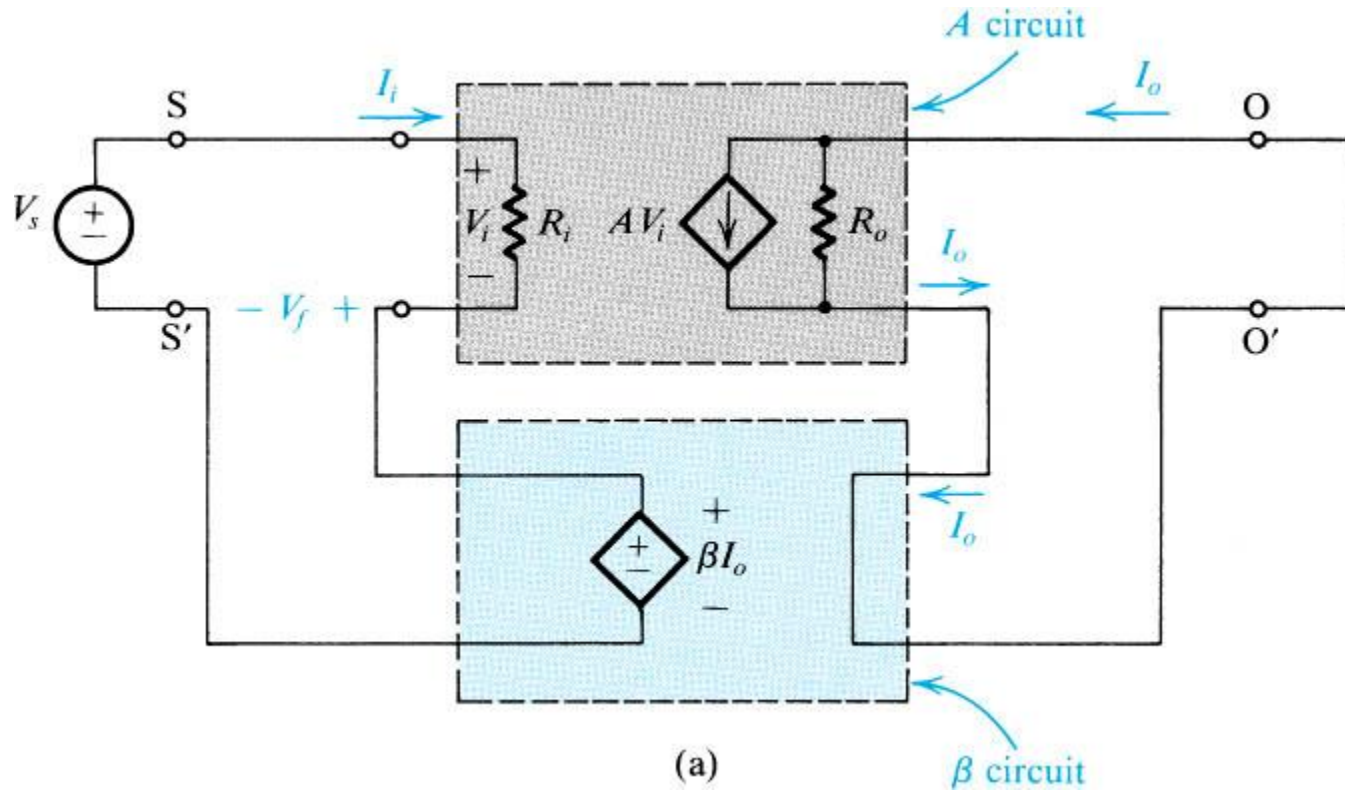
(c)

$$\beta \equiv \frac{V_f}{V_s} = \frac{R_1}{R_1 + R_2}$$

The Series-Series Feedback Amplifier

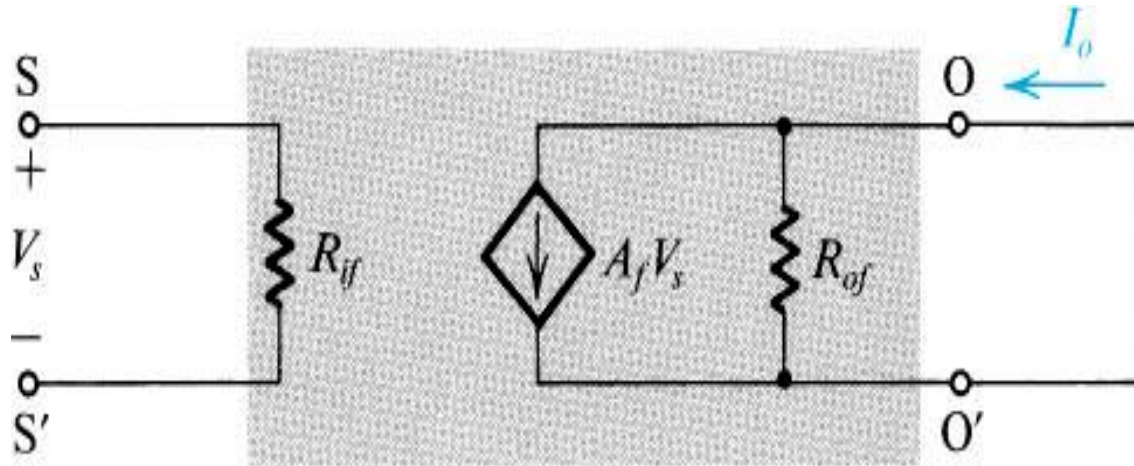
- The ideal situation
- The practical situation
- summary

The Ideal Situation



Trans conductance gain $A \equiv \frac{I_o}{V_i}$

The Ideal Situation



(b)

Transresistance feedback factor $\beta \equiv \frac{V_f}{I_o}$

Input and Output Resistance with Feedback

- Input resistance

$$R_{if} = R_i (1 + A\beta)$$

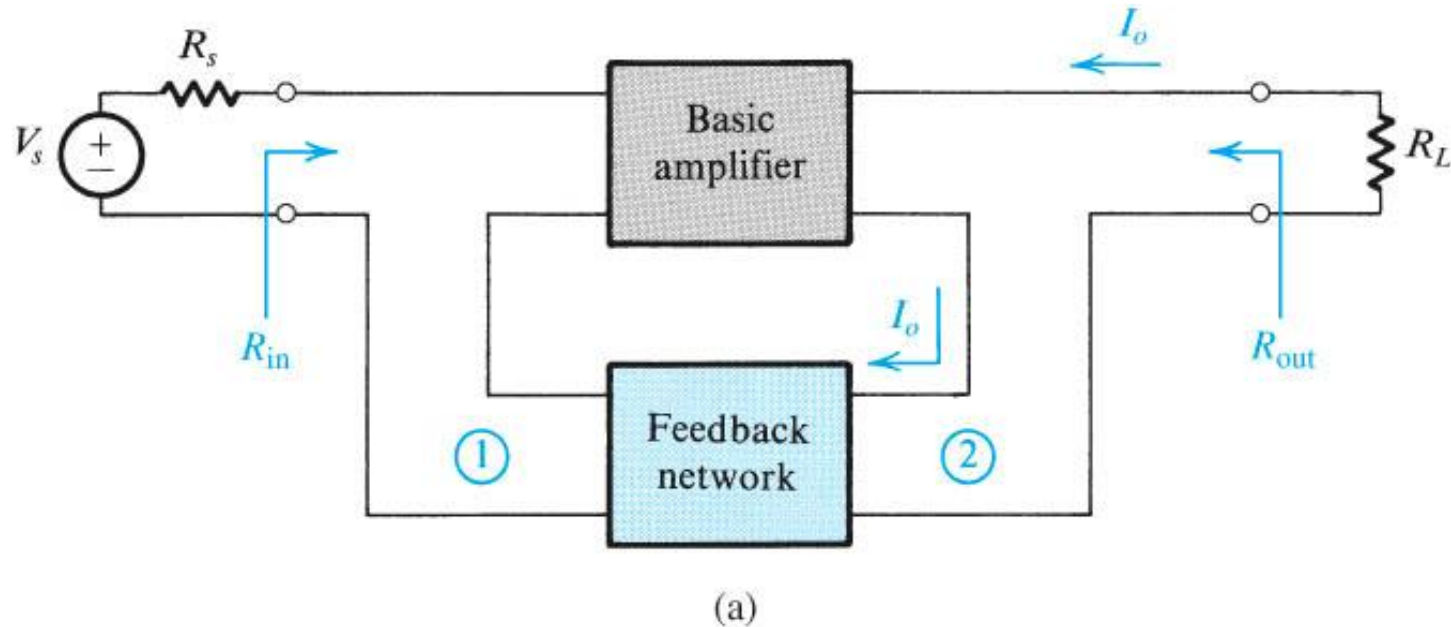
In this case, the negative feedback increases the input resistance by a factor equal to the amount of feedback.

- Output resistance

$$R_{of} = R_o (1 + A\beta)$$

In this case, the negative feedback increases the output resistance by a factor equal to the amount of feedback.

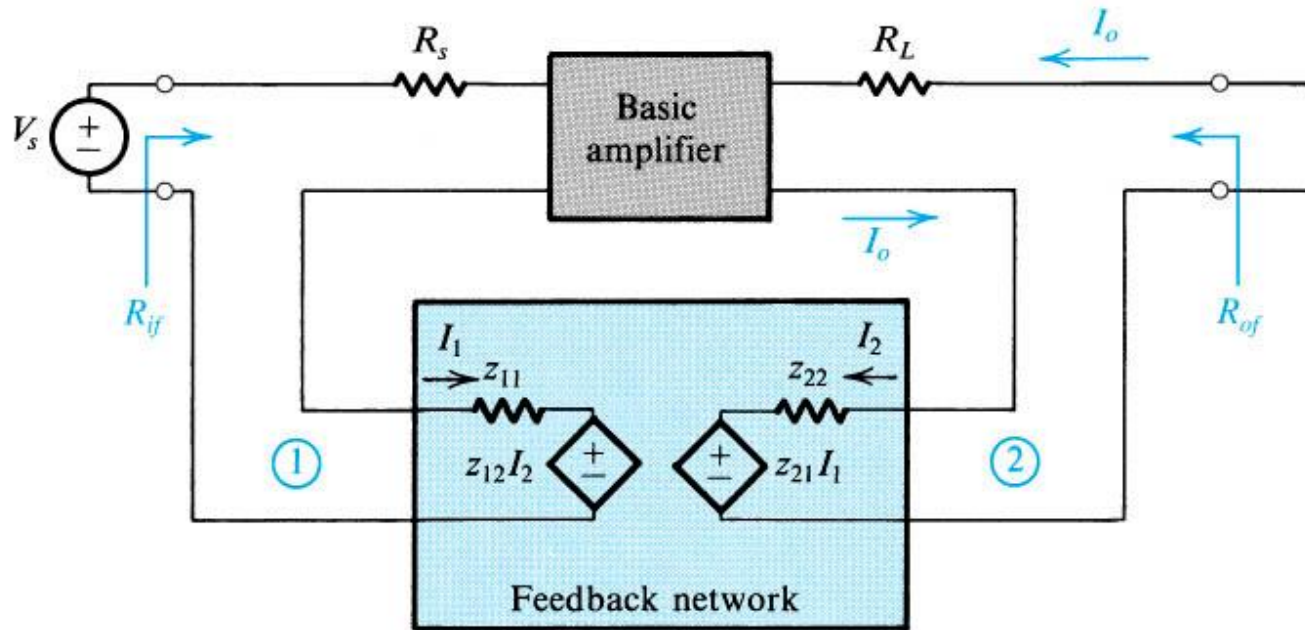
The Practical Situation



Block diagram of a practical series-series feedback amplifier.

- Feedback network is not ideal and load the basic amplifier thus affect the values of gain, input resistance and output resistance.

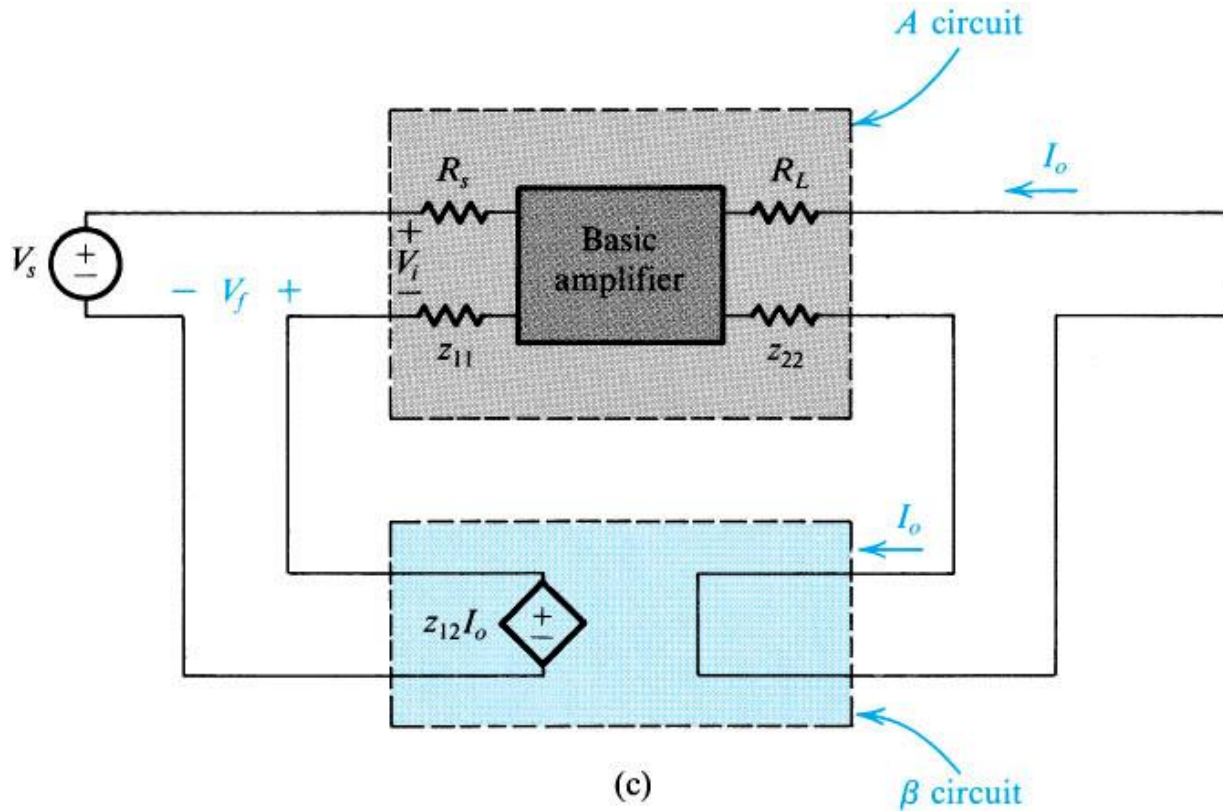
The Practical Situation



(b)

The circuit of (a) with the feedback network represented by its z parameters.

The Practical Situation



A redrawing of the circuit in (b) with z_{21} neglected.

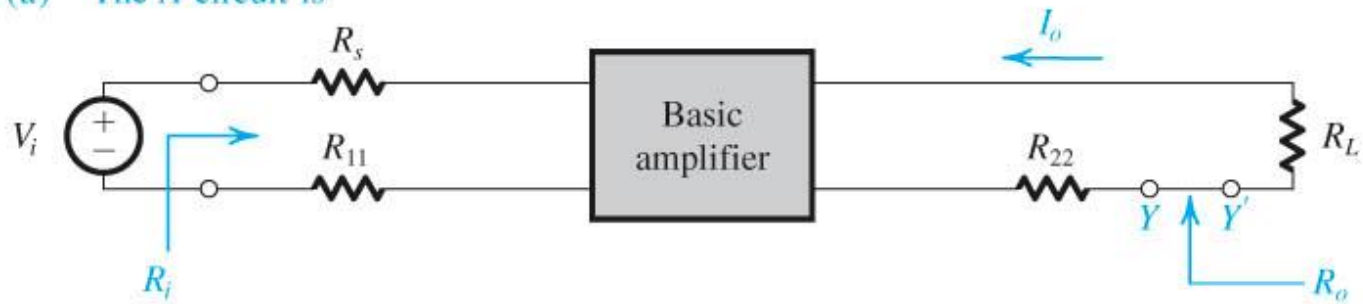
The Practical Situation

- The load effect of the feedback network on the basic amplifier is represented by the components Z_{11} and Z_{22} .
- Z_{11} is the impedance looking into port 1 of the feedback network with port 2 open-circuited.

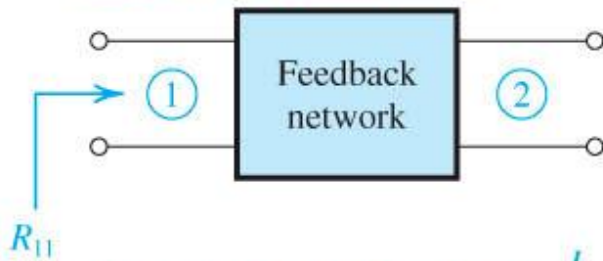
- Z_{22} is the impedance looking into port 2 of the feedback network with port 1 open-circuited.
- Determine the β .

$$\beta = z_{12} \equiv \left. \frac{V_1}{I_2} \right|_{I_1=0}$$

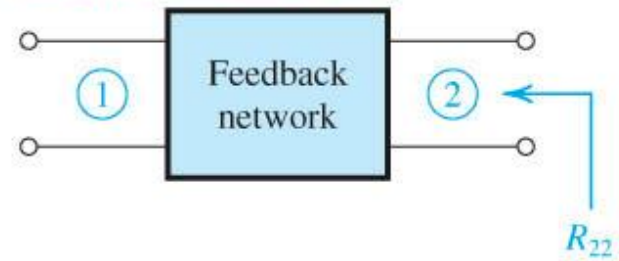
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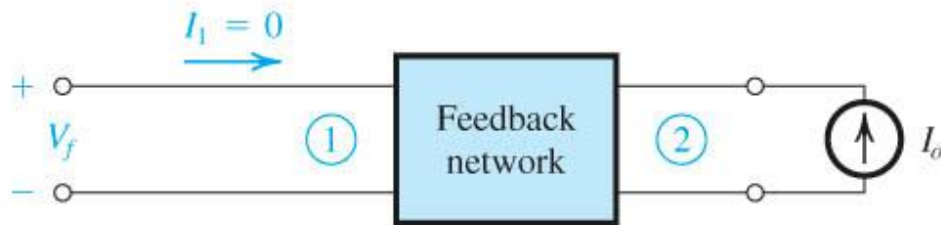


and R_{22} is obtained from



and the gain A is defined $A \equiv \frac{I_o}{V_i}$

(b) β is obtained from



$$\beta \equiv \left. \frac{V_f}{I_o} \right|_{I_1 = 0}$$

Summary

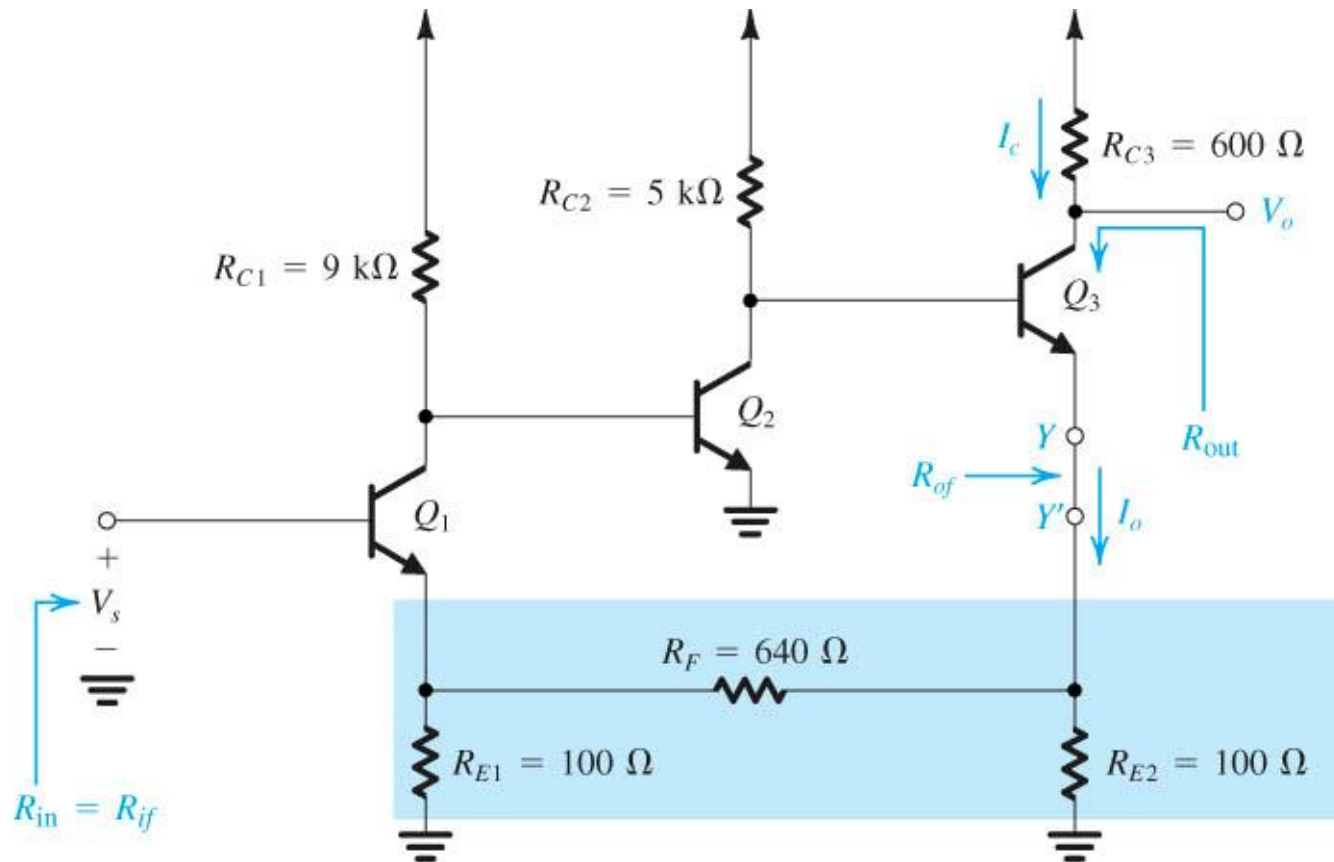
- R_i and R_o are the input and output resistances, respectively, of the A circuit.
- R_{if} and R_{of} are the input and output resistances, respectively, of the feedback amplifier, including R_s and R_L .

- The actual input and output resistances exclude R_s and R_L .

$$R_{if} = R_{in} + R_s$$

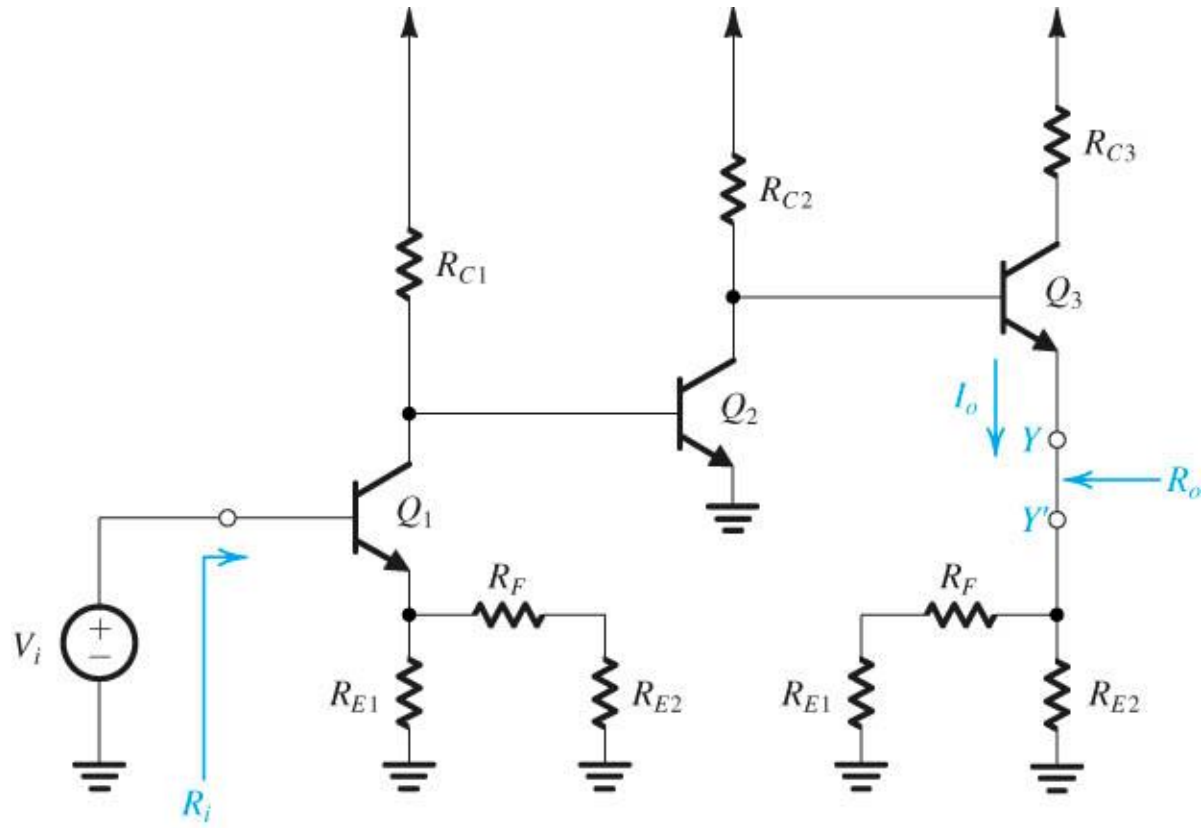
$$R_{of}' = R_{out} + R_L$$

Example of Series-Series Feedback Amplifier



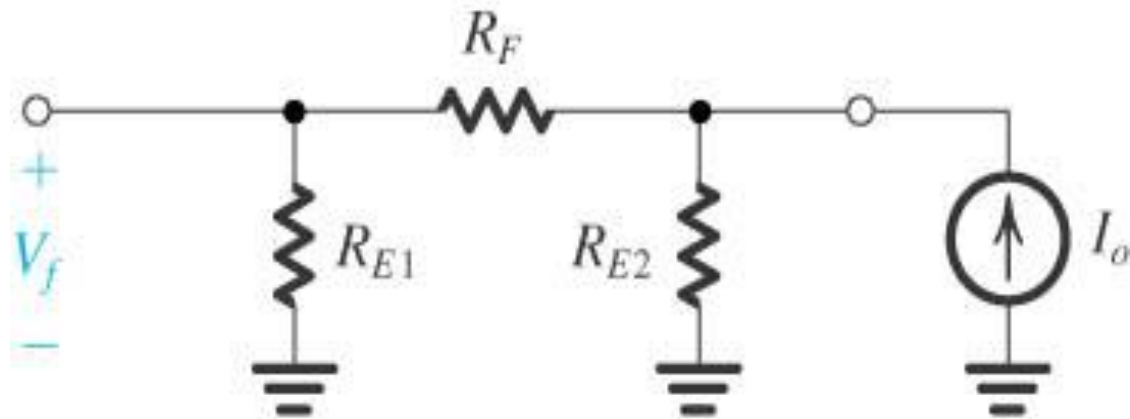
(a)

Example of Series-Series Feedback Amplifier



(b)

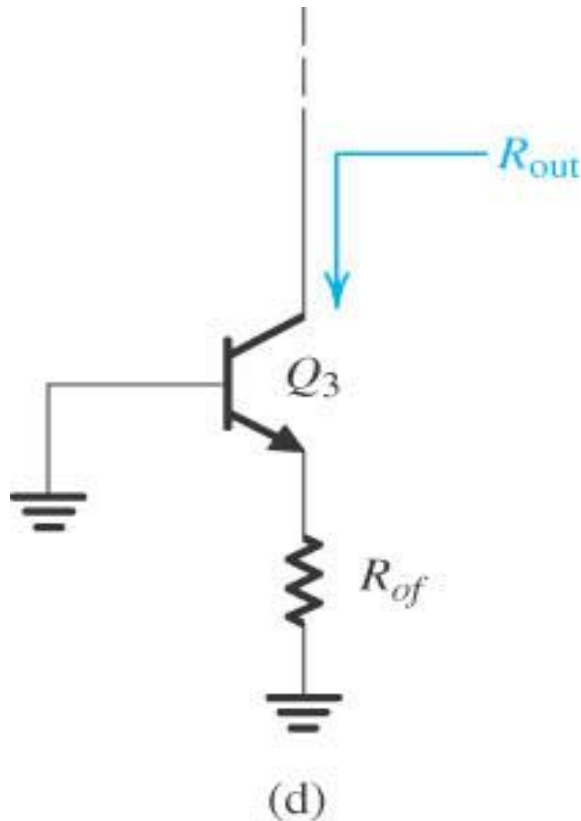
Example of Series-Series Feedback Amplifier



(c)

$$\beta \equiv \frac{V_f}{I_o} = \frac{R_{E2}}{R_{E2} + R_F + R_{E1}} \times R_{E1}$$

Example of Series-Series Feedback Amplifier



$$R_o = \left[R_{E2} \parallel (R_F + R_{E1}) \right] + r_{e3} + \frac{R_{C2}}{1 + h_{fe}}$$

$$R_{of} = R_o (1 + A\beta)$$

$$R_{out} = r_o + (1 + g_{m3}r_o)(R_{of} \parallel r_{\pi3})$$

The Shunt-Shunt and Shunt-Series Feedback Amplifiers

- Study by yourselves
- Important notes:
 - Closed-loop gain
 - Feedback factor
 - Load effect
 - Summary
 - example

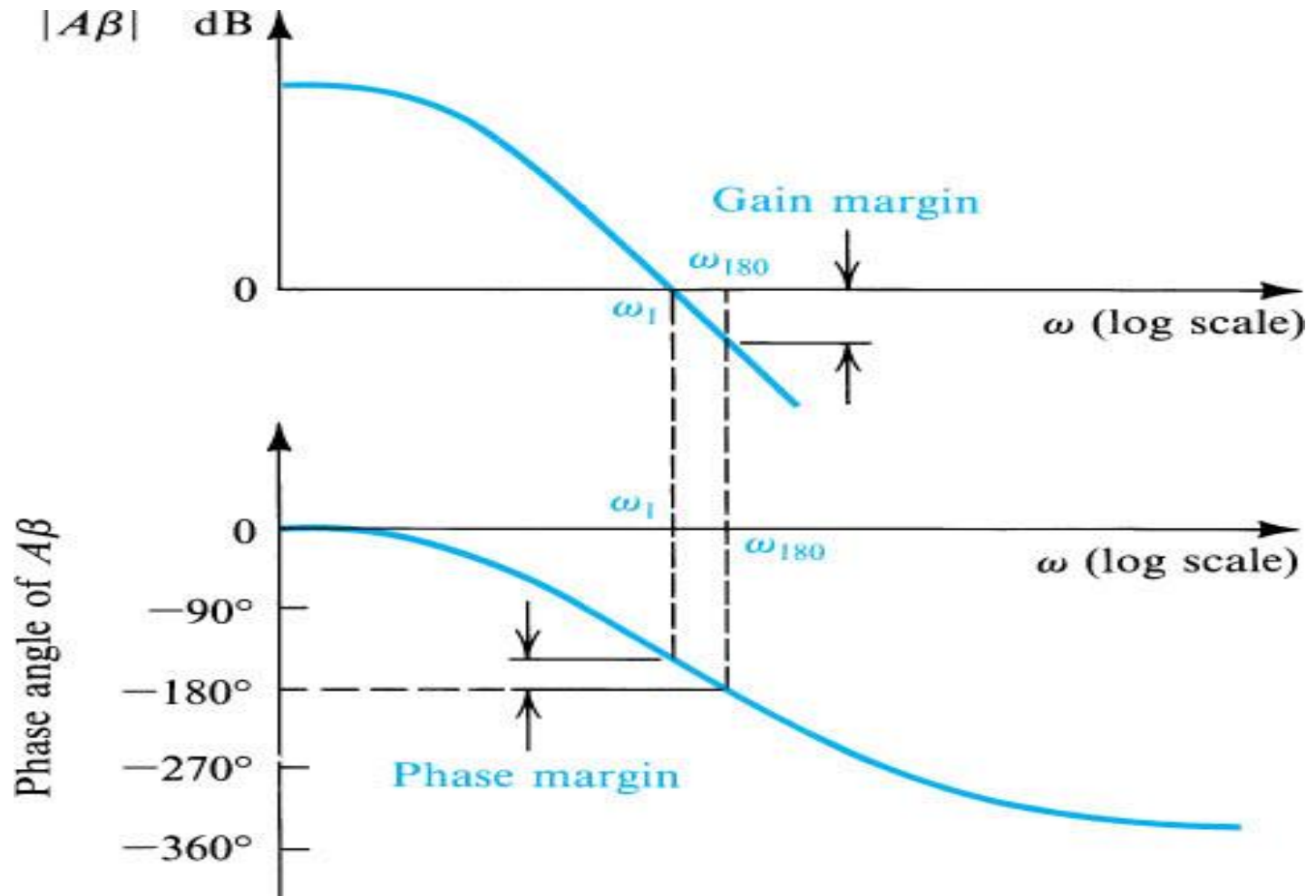
The Stability Problem

- Closed-loop transfer function is similar to the one of the middle band gain.
- The condition for feedback to oscillate

$$L(j\omega) = A(j\omega)\beta(j\omega) = -1$$

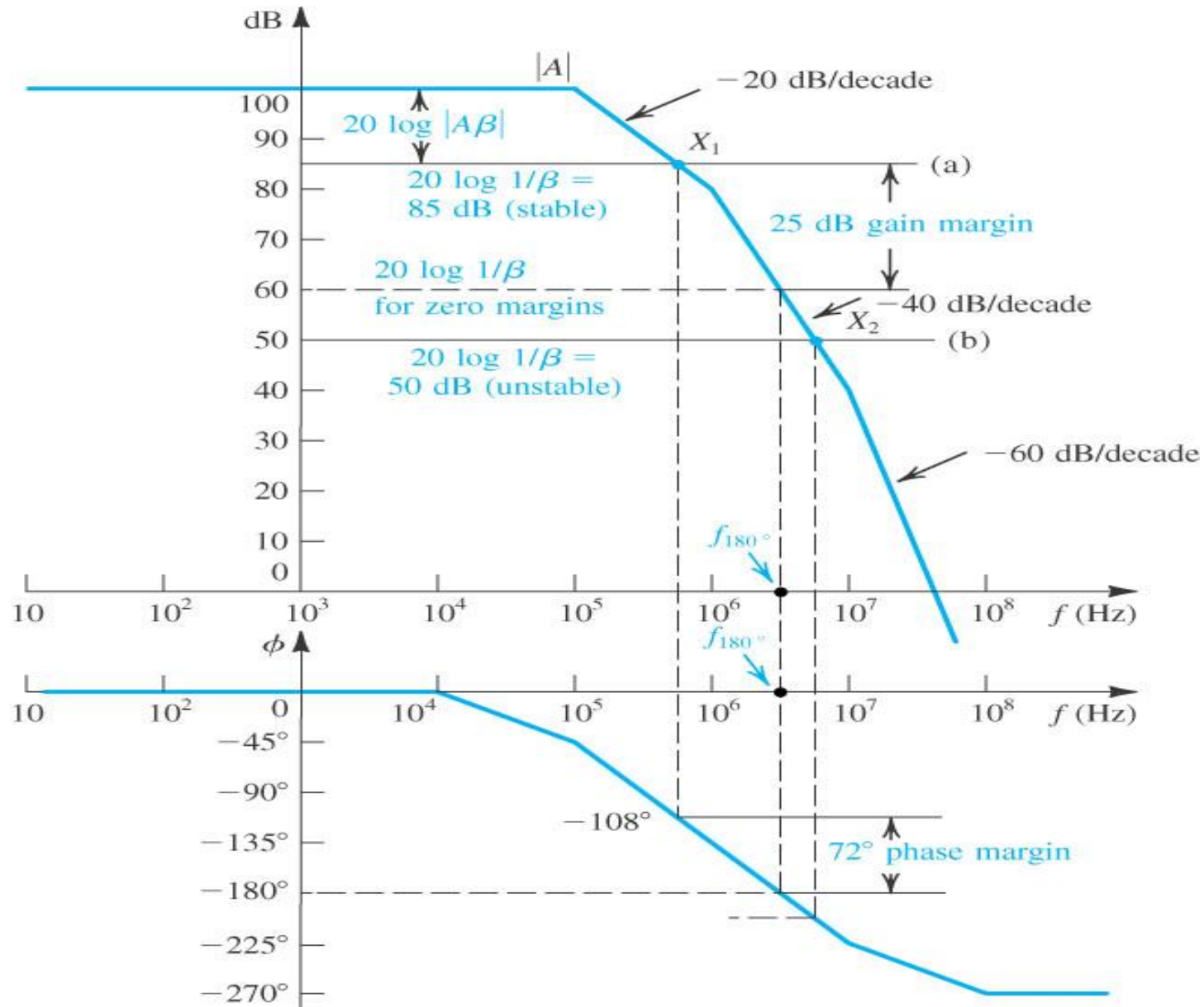
- Any right-half-plane poles results in instability.
 - Amplifier with a single-pole is unconditionally stable.
 - Amplifier with two-pole is also unconditionally stable.
 - Amplifier with more than two poles has the possibility to be unstable.
- Stability study using bode plot

The Definitions of the Gain and Phase margins



- Gain margin represents the amount by which the loop gain can be increased while stability is maintained.
- Unstable and oscillatory
- Stable and non-oscillatory
- Only when the phase margin exceed 45° or gain margin exceed 6dB, can the amplifier be stable.

Stability analysis using Bode plot of $|A|$



Stability Analysis Using Bode Plot of $|A|$

- Gain margin and phase margin
- The horizontal line of inverse of feedback factor in dB.
- A rule of thumb:

The closed-loop amplifier will be stable if the $20\log(1/\beta)$ line intersects the $20\log|A|$ curve at a point on the -20dB/decade segment.

- The general rule states:

At the intersection of $20\log[1/|\beta(j\omega)|]$ and $20\log|A(j\omega)|$ the difference of slopes should not exceed 20dB/decade.

Frequency Compensation

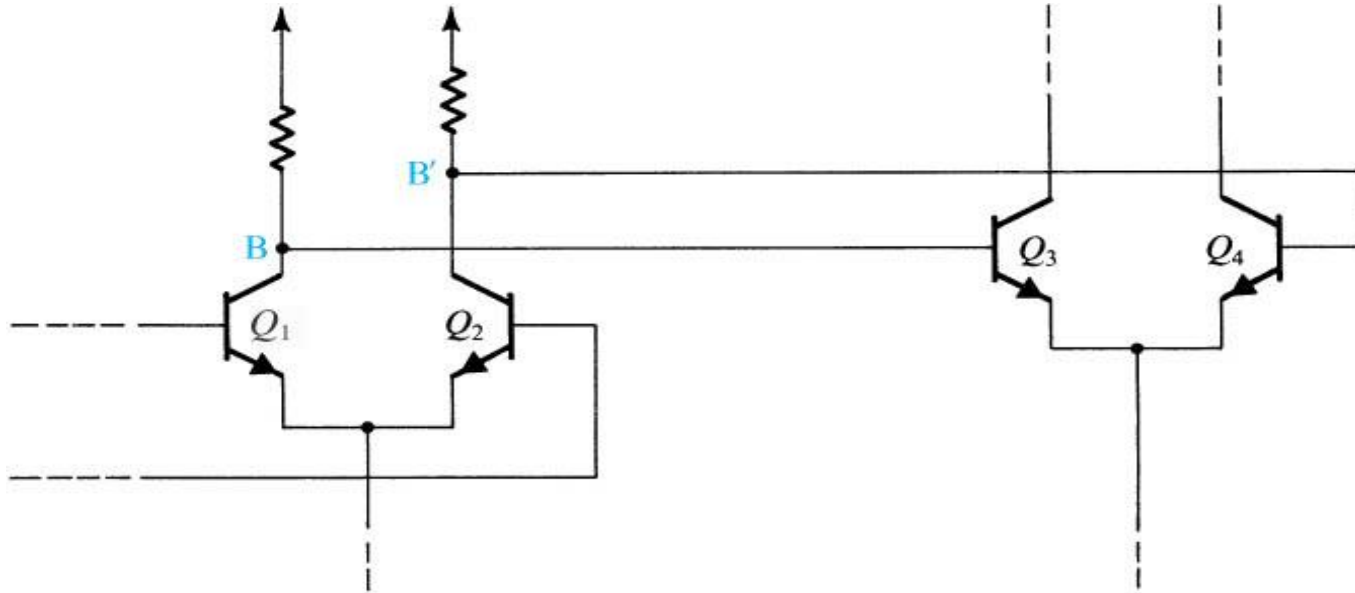
- The purpose is to modifying the open-loop transfer function of an amplifier having three or more poles so that the closed-loop amplifier is stable for any desired value of closed-loop gain.
- Theory of frequency compensation is the enlarge the -20dB/decade line.

- Implementation

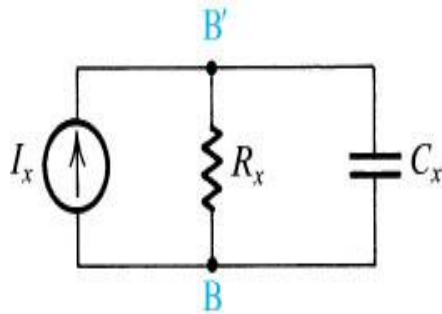
- Capacitance C_c added

- Miller compensation and pole splitting

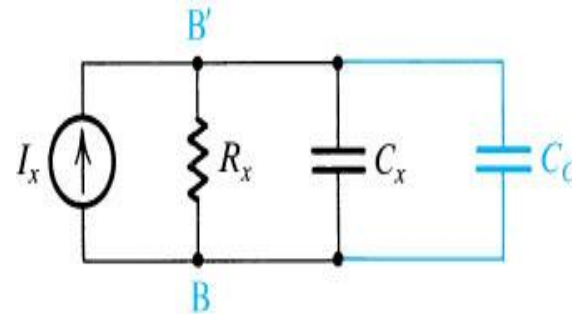
Frequency Compensation



(a)

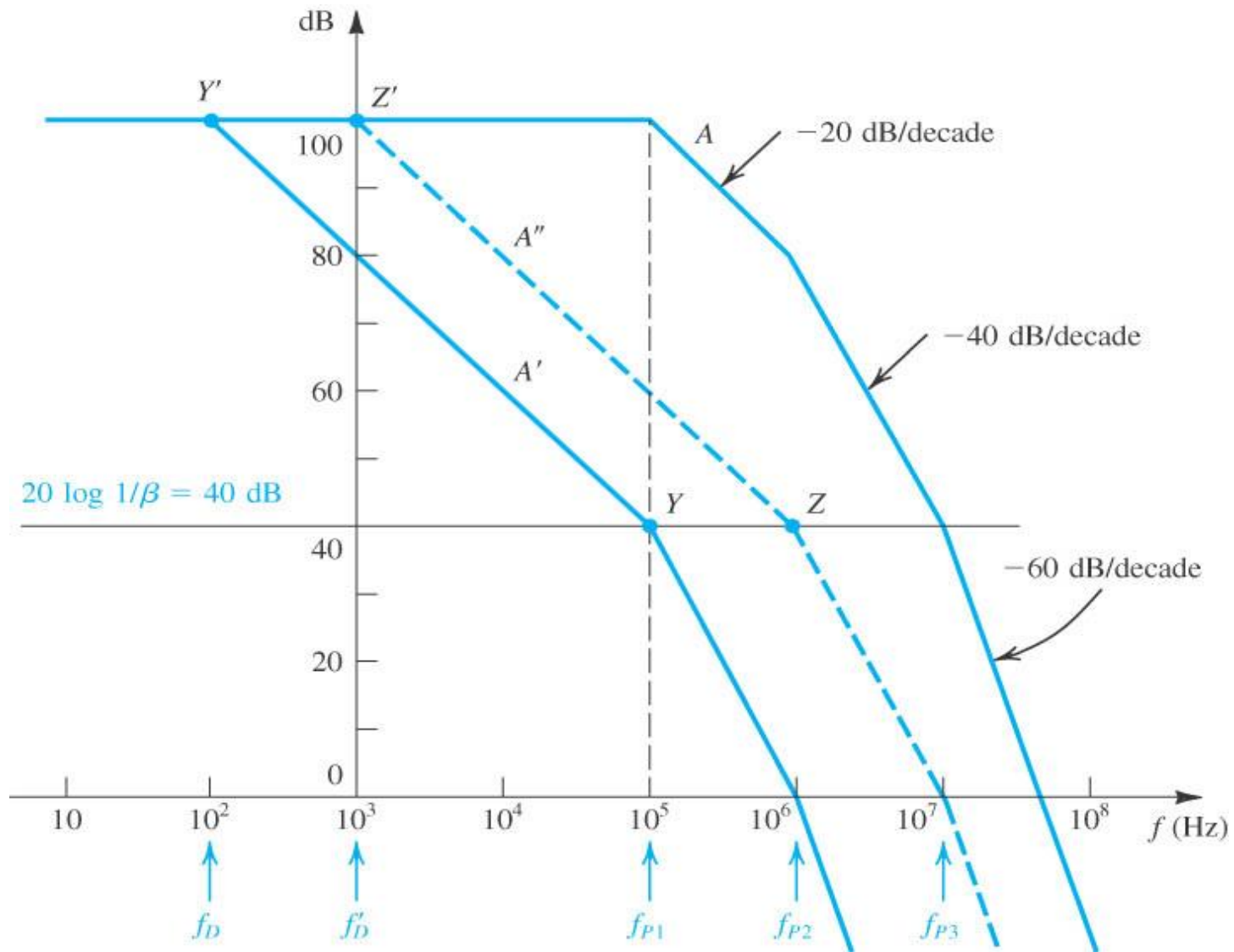


(b)



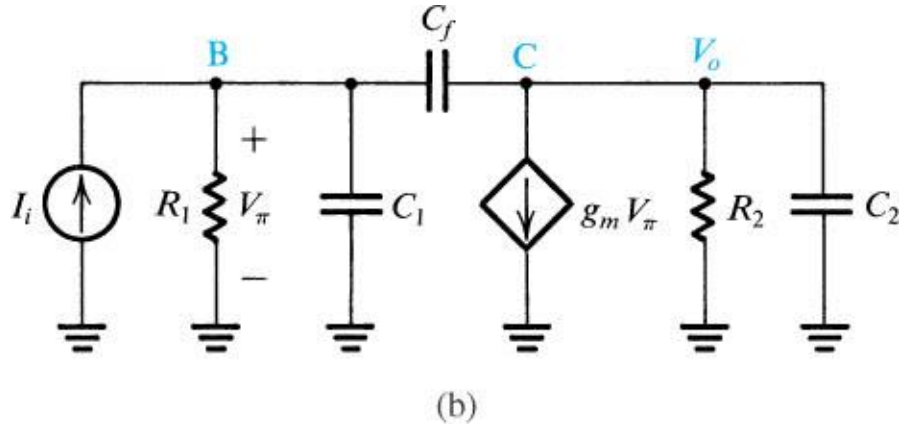
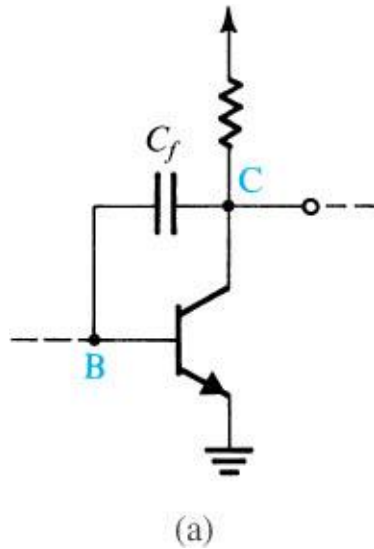
(c)

- Two cascaded gain stages of a multistage amplifier.
- Equivalent circuit for the interface between the two stages in (a).
- Same circuit as in (b) but with a compensating capacitor C_C added.



- Frequency compensation for $\beta = 10^{-2}$. The response labeled A' is obtained by introducing an additional pole at f_D . The A'' response is obtained by moving the original low-frequency pole to f'_D .

Frequency Compensation



- A gain stage in a multistage amplifier with a compensating capacitor connected in the feedback path
- An equivalent circuit.