Feedback Amplifiers

Outline

- Introduction
- The general feedback structure
- Some properties of negative feedback
- The four basic feedback topologies
- The series-shunt feedback amplifier
- The series-series feedback amplifier
- The shunt-shunt and shunt-series feedback amplifier

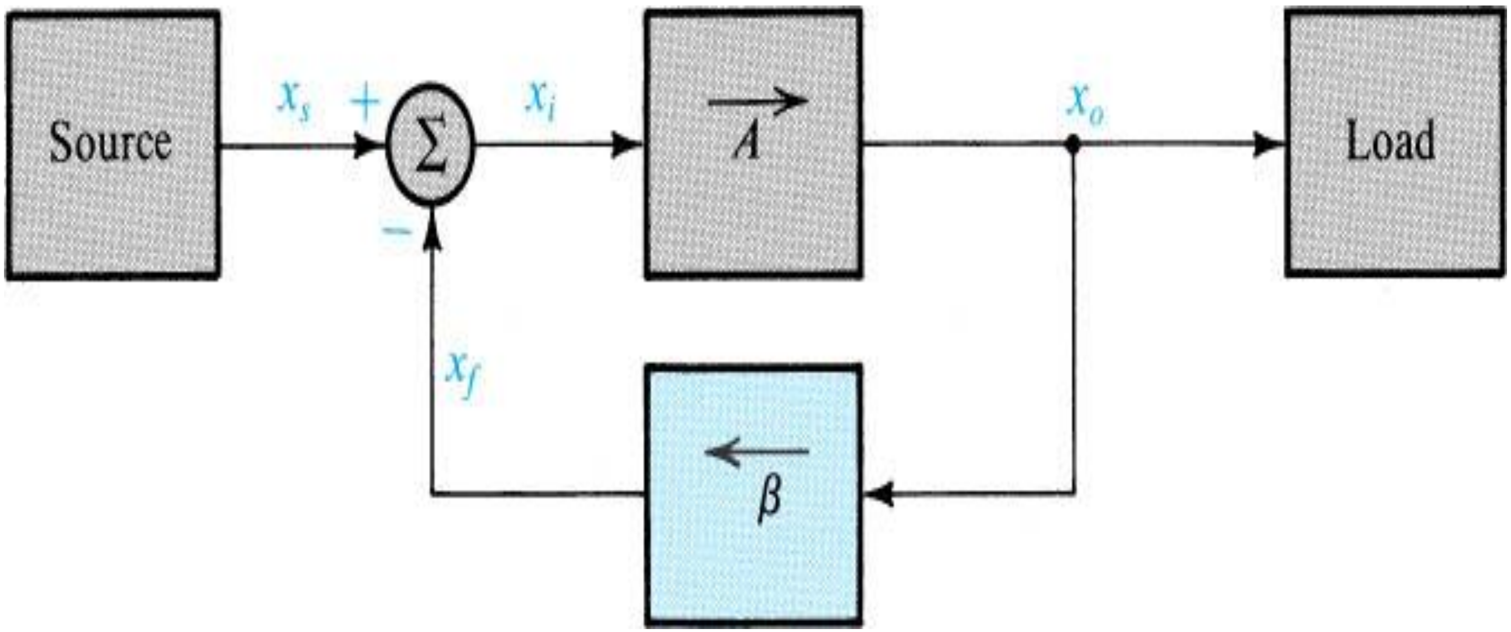
- The stability problem
- Stability study using bode plot
- Frequency compensation

Introduction

- It's impossible to think of electronic circuits without some forms of feedback.
- Negative feedback
  - ➢ Desensitize the gain
  - ➢ Reduce nonlinear distortion
  - ➢ Reduce the effect of noise
  - ➢ Control the input and output impedance
  - ➢ Extend the bandwidth of the amplifier

- *The basic idea of negative feedback is to trade off gain for other desirable properties.*
- Positive feedback will cause the amplifier oscillation.

The General Feedback Structure



This is a signal-flow diagram, and the quantities *x* represent either voltage or current signals.

The General Feedback Equation

- Closed loop and open loop
- Closed loop gain

$$A_f \equiv \frac{x_o}{x_s} = \frac{A}{1 + A\beta}$$

- Feedback factor β
- Loop gain $A\beta$
- Amount of feedback $(1 + A\beta)$

Some Properties of Negative Feedback

- Gain desensitivity

$$\frac{dA_f}{A_f} = \frac{1}{1 + A\beta} \frac{dA}{A}$$

- Bandwidth extension
- Noise reduction
- Reduction in nonlinear distortion

The Four Basic Feedback Topologies

- **Voltage amplifier---**series-shunt feedback

  voltage mixing and voltage sampling
- **Current amplifier---**shunt-series feedback

  Current mixing and current sampling

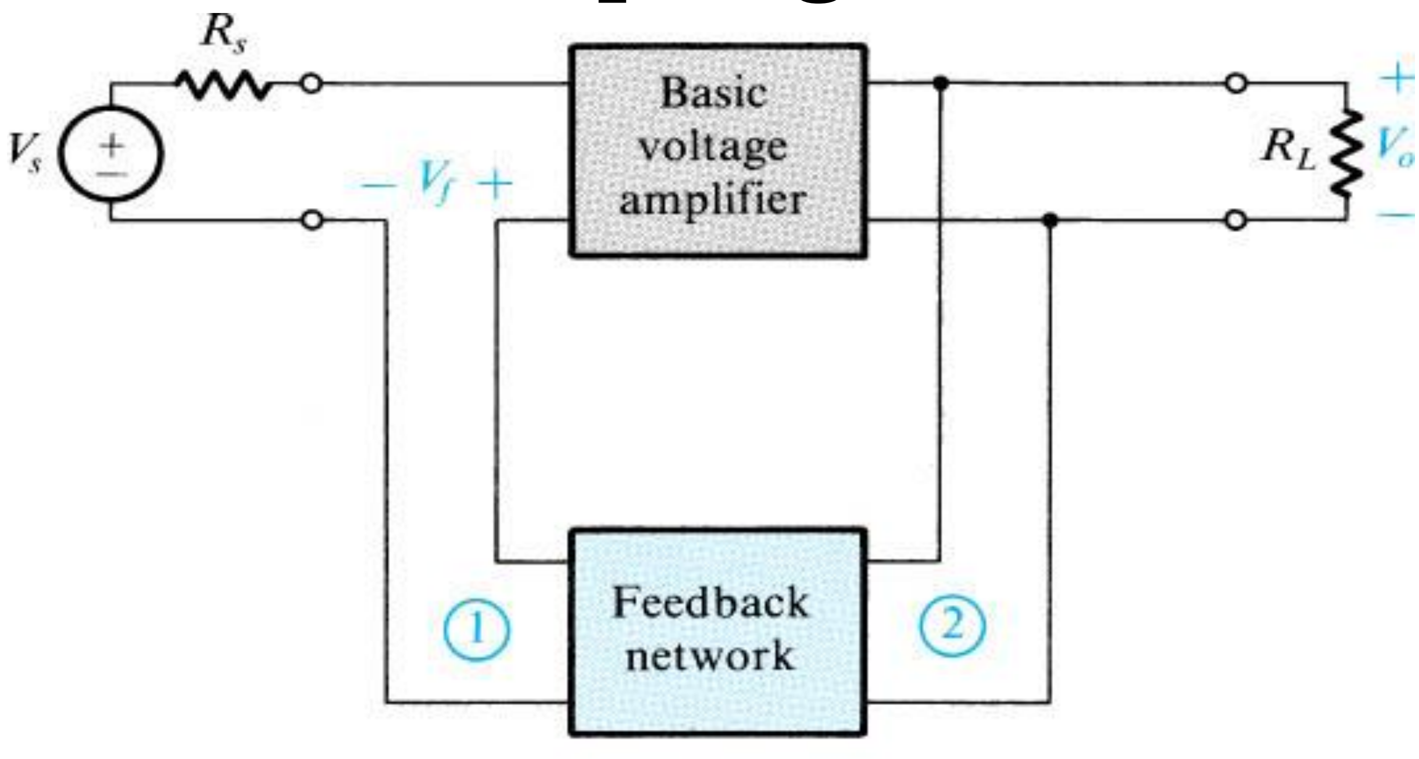
- **Transconducatnce amplifier---**series-series feedback

  Voltage mixing and current sampling

- **Transresistance amplifier---**shunt-shunt feedback

  Current mixing and voltage sampling

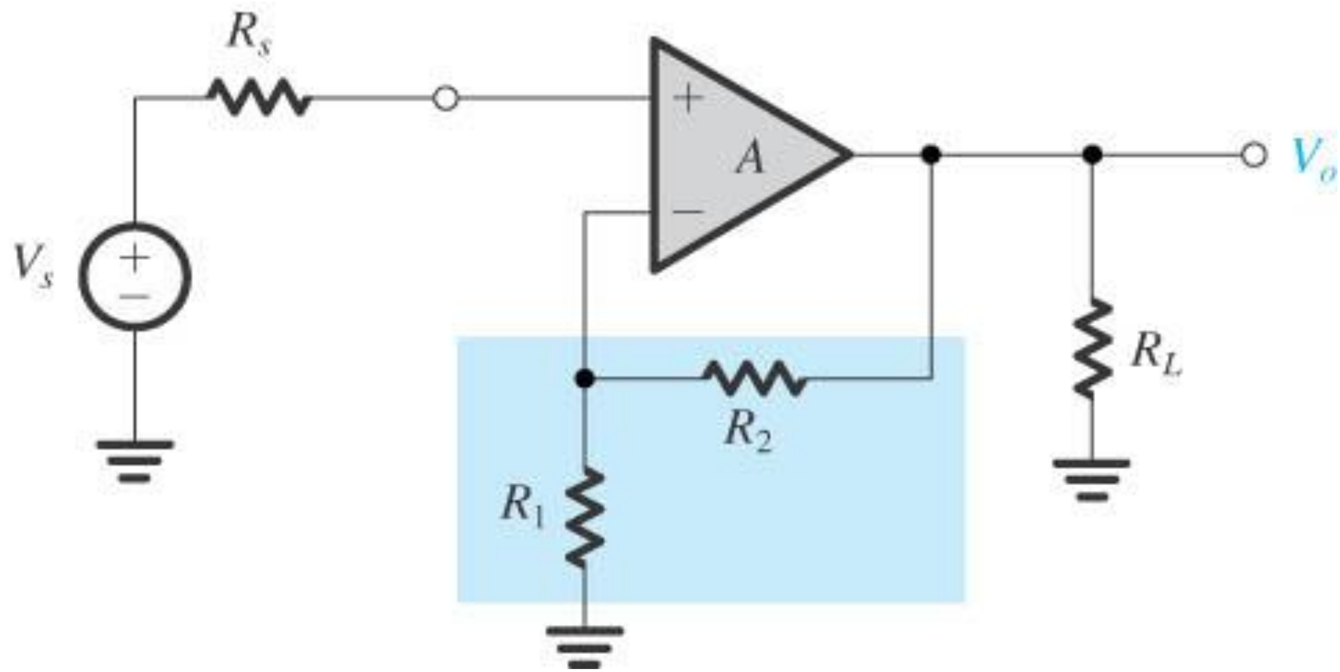
The Series-Shunt Feedback Topologies



(a)

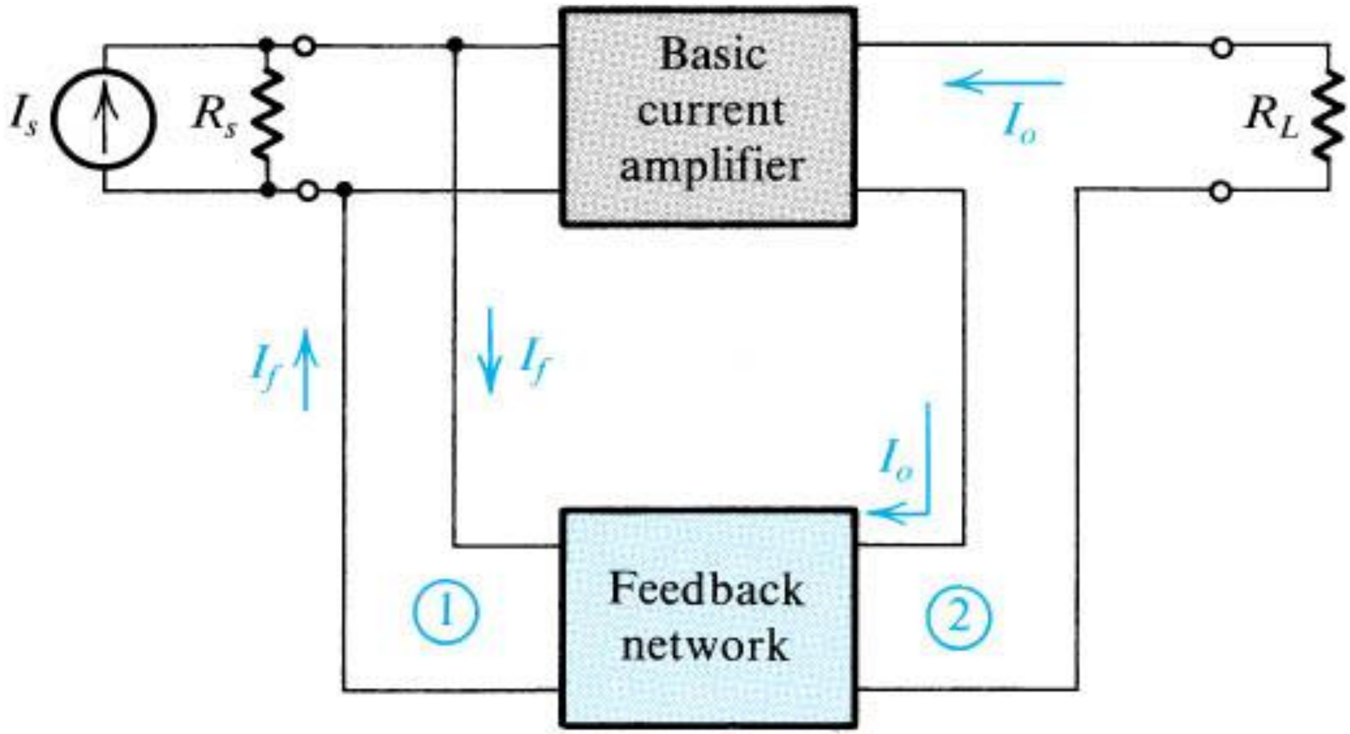
voltage-mixing voltage-sampling (series–shunt) topology

The Amplifier with Series-Shunt Feedback



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

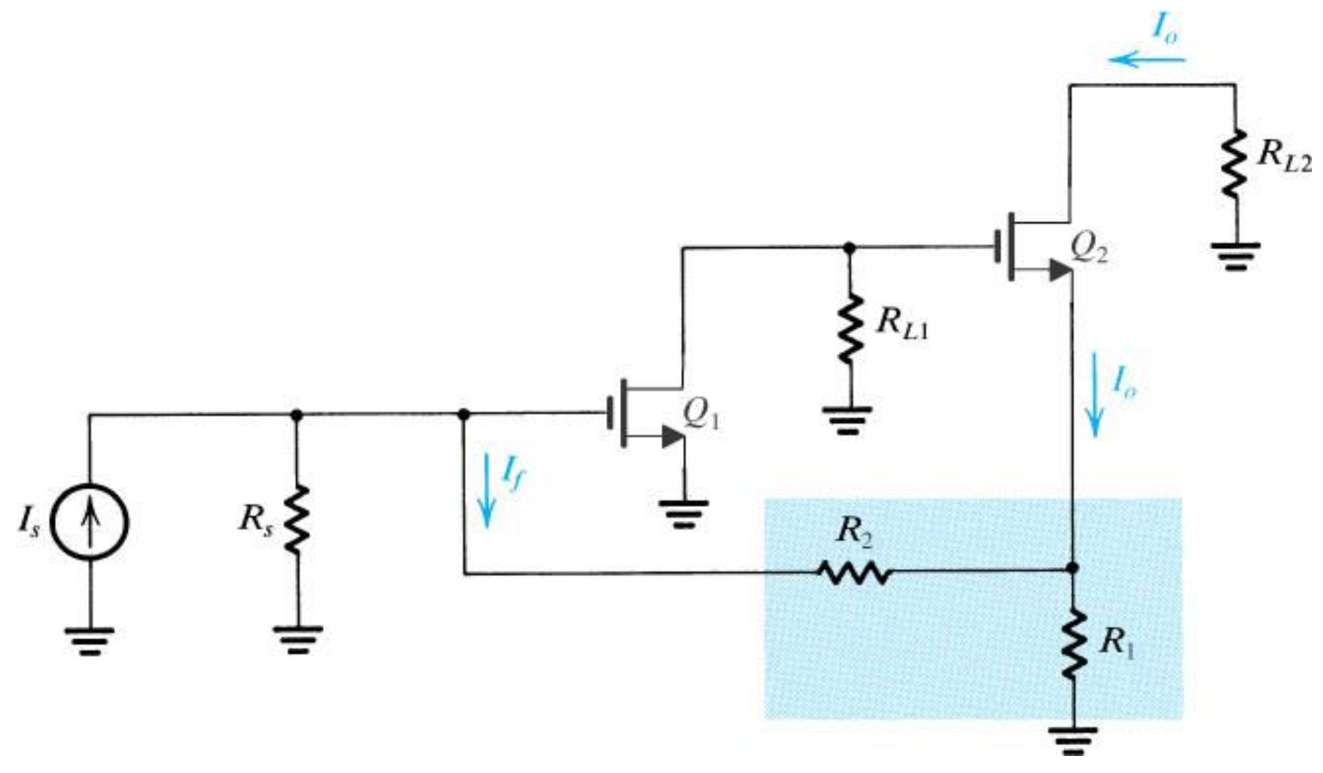
The Shunt-Series Feedback Topologies



(b)

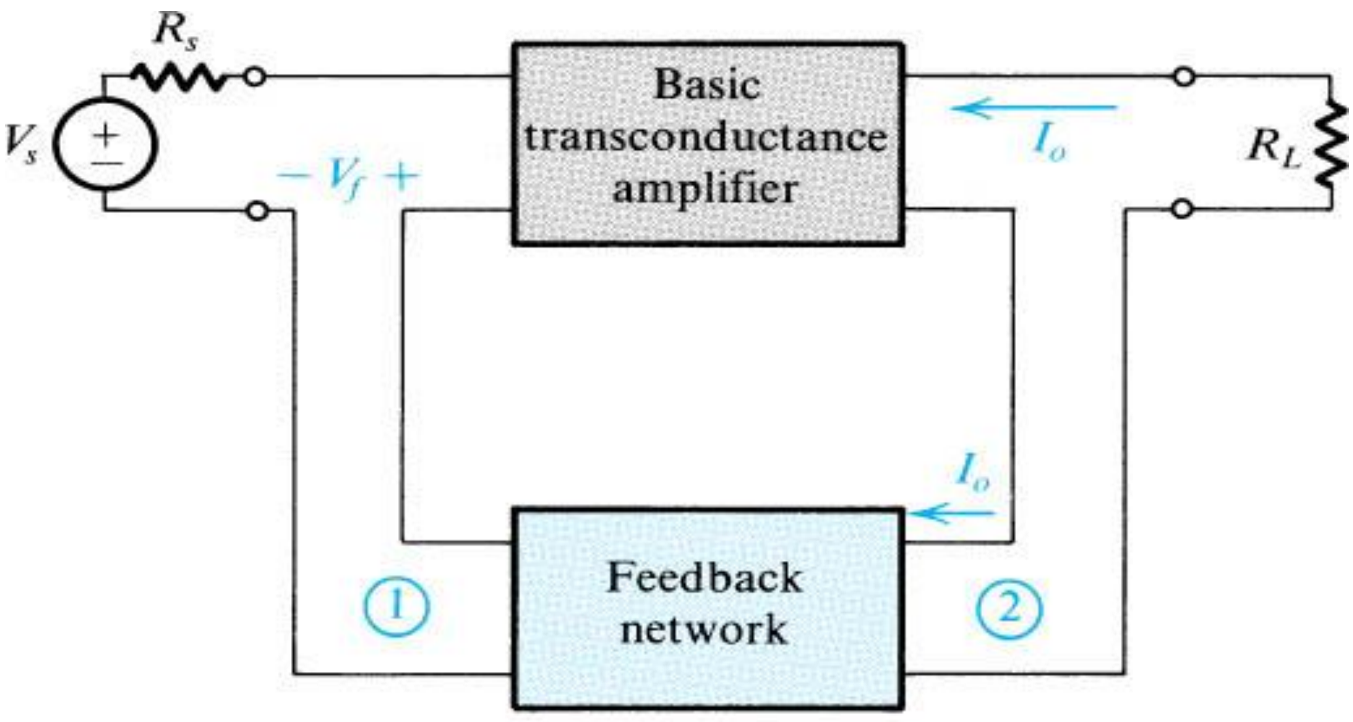
current-mixing current-sampling (shunt–series) topology

The Amplifier with Shunt-Series Feedback



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

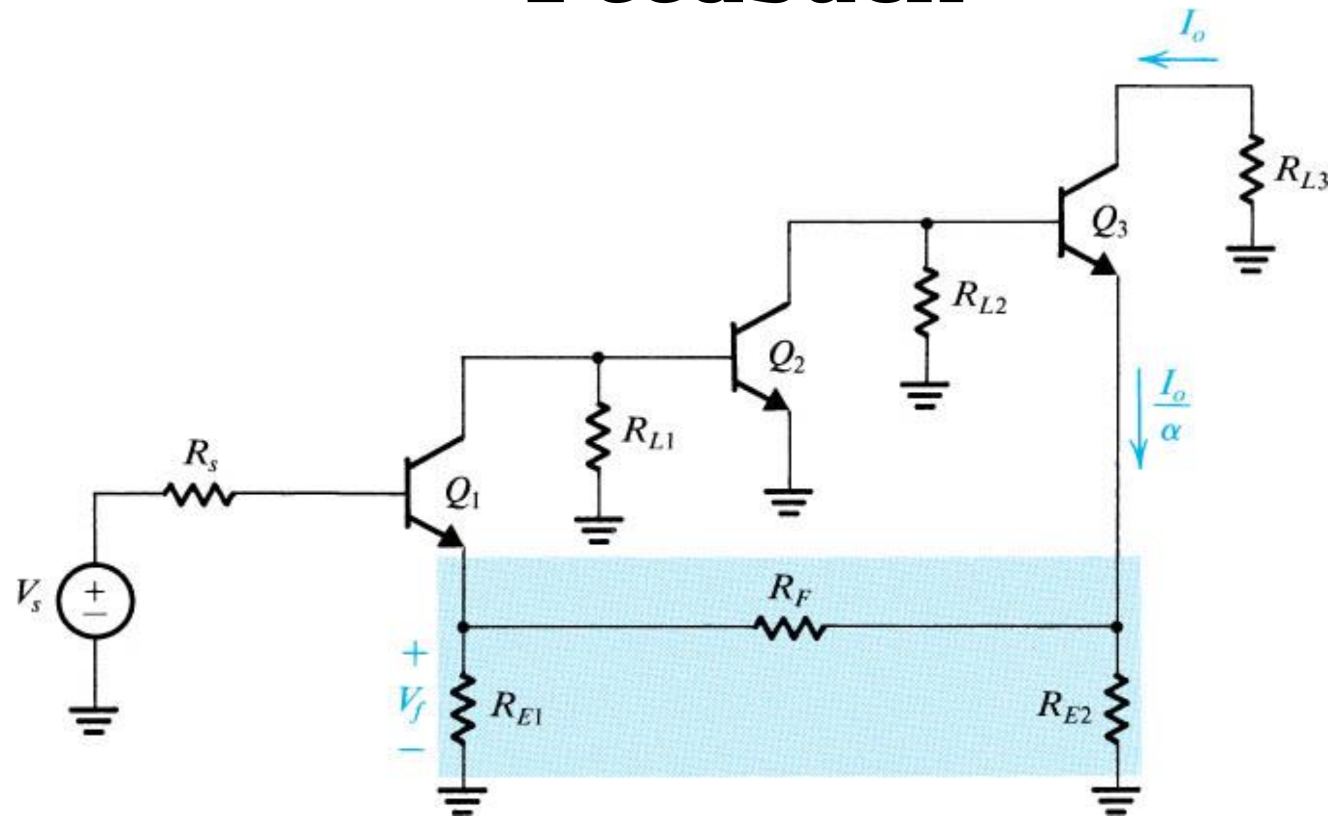
The Series-Series Feedback Topologies



(c)

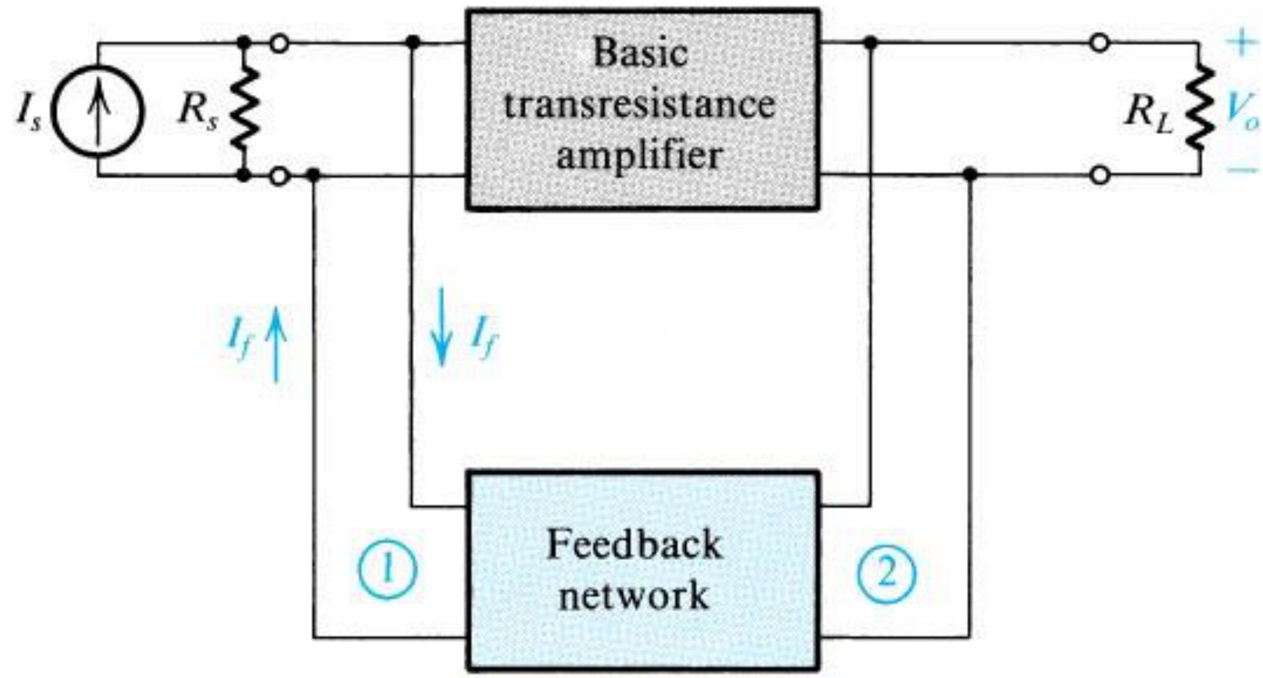
voltage-mixing current-sampling (series–series) topology

The Amplifier with Series-Series Feedback



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

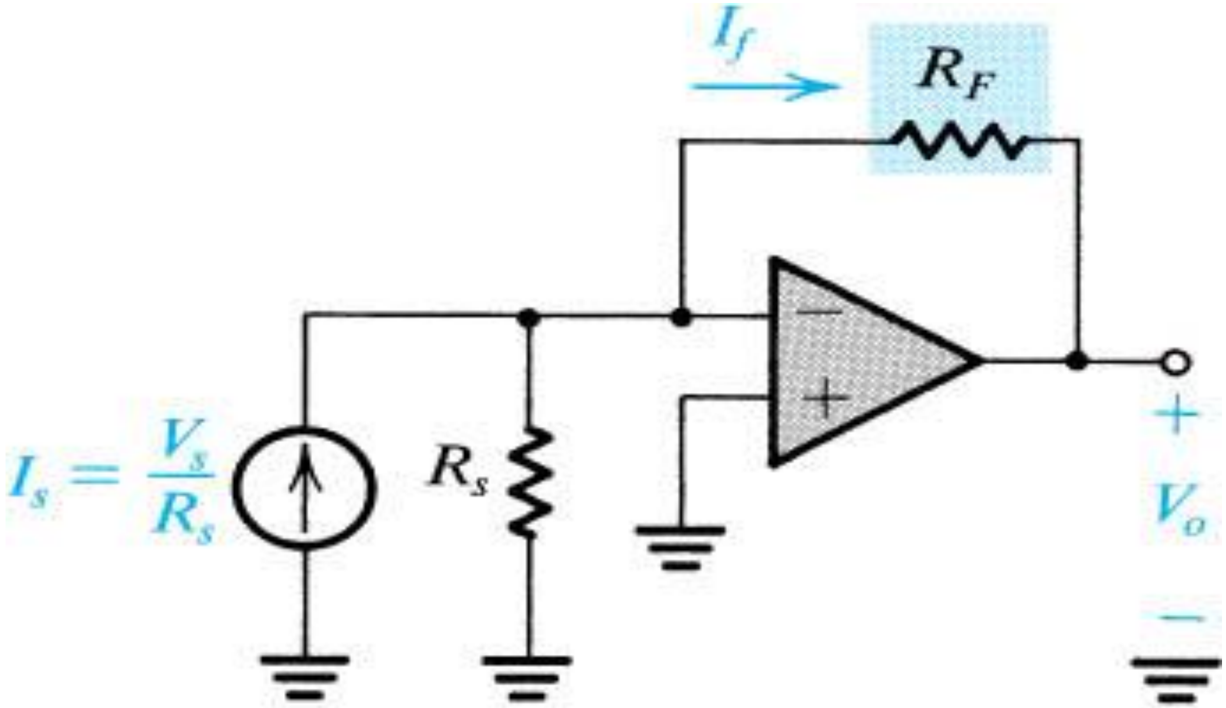
The Shunt-Shunt Feedback Topologies



(d)

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

The OP Amplifier with Shunt-Shunt Feedback



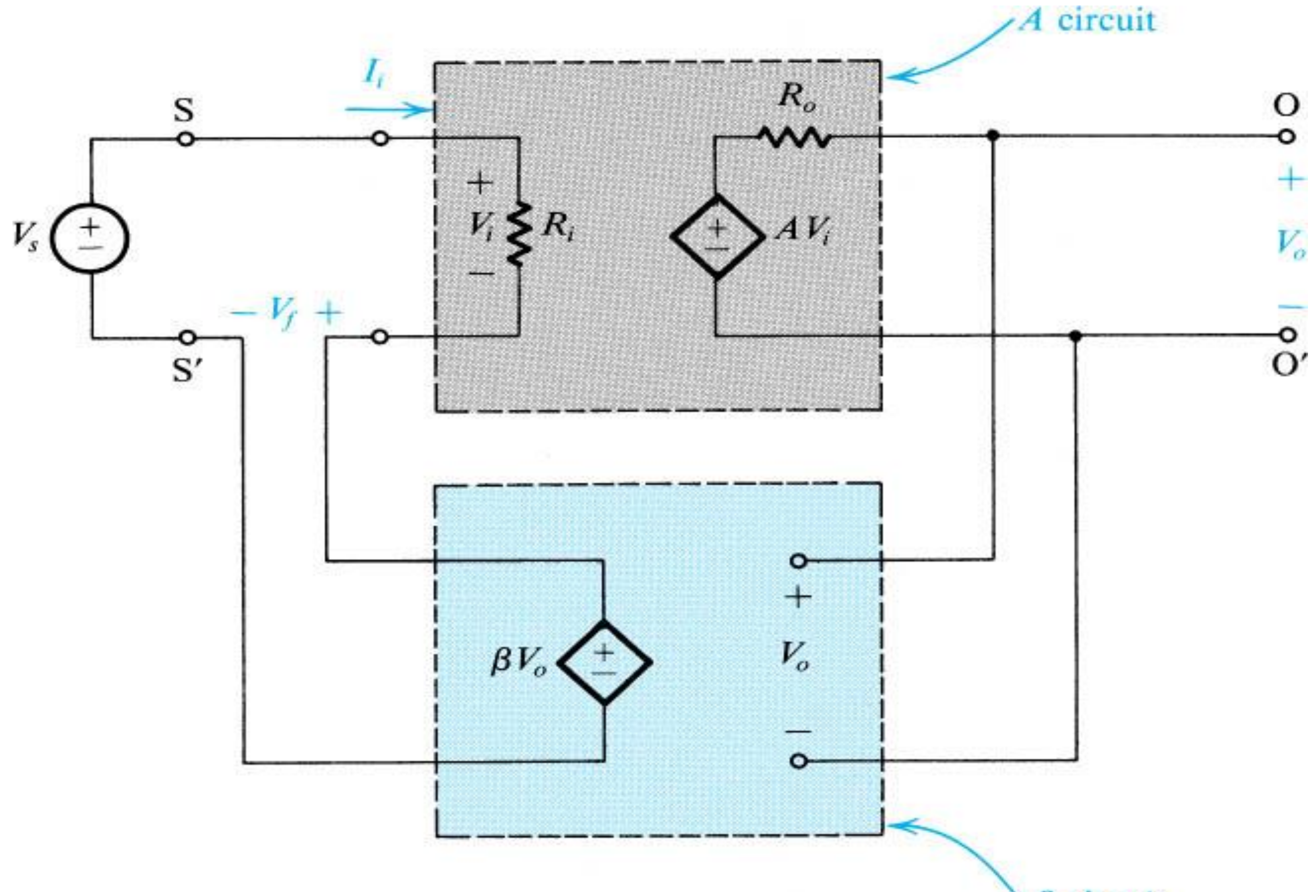
(b)

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

The Series-Shunt Feedback Amplifier

- The ideal situation
- The practical situation
- summary

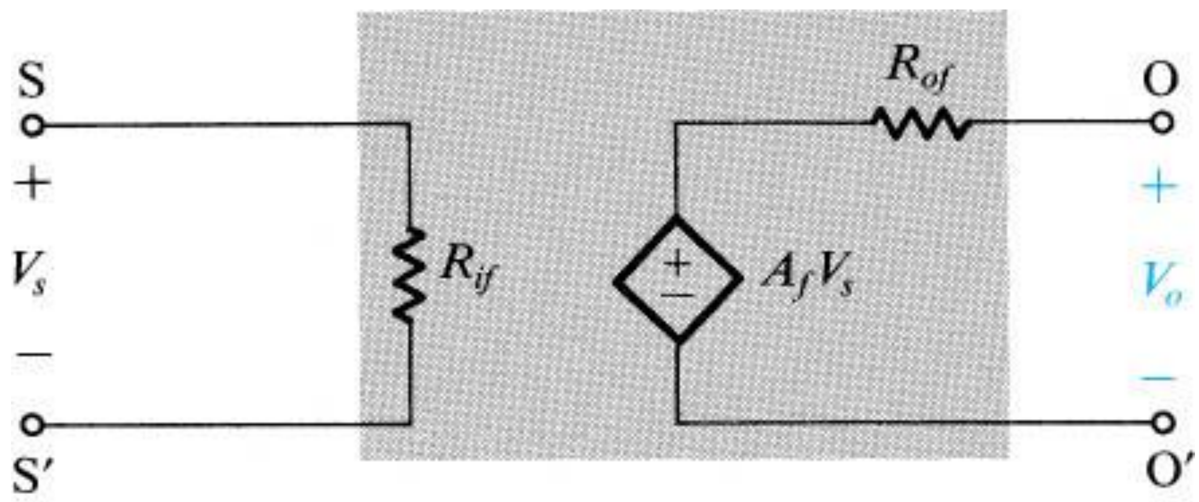
The Ideal Situation



(a)

- 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



(b)

Equivalent circuit.

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

Input and Output Resistance with Feedback

- Input resistance

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

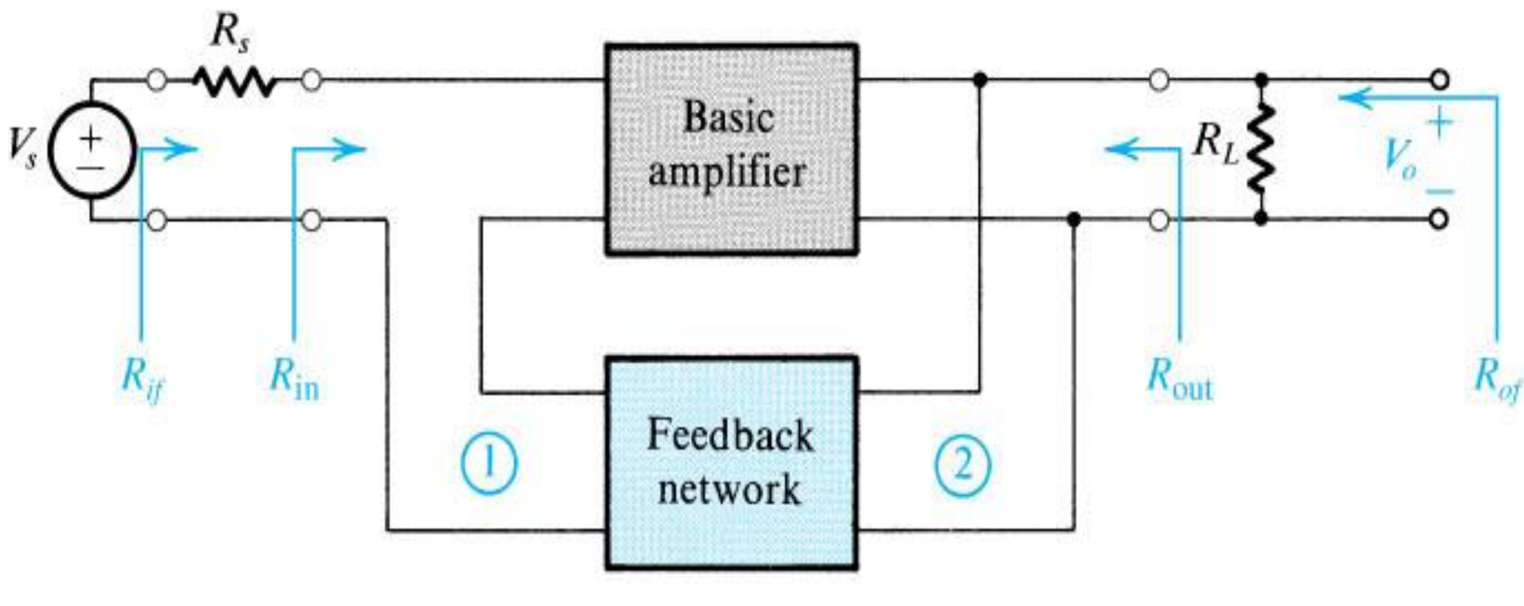
In this case, the negative feedback increases the input resistance by a factor equal to the amount of feedback.

- 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

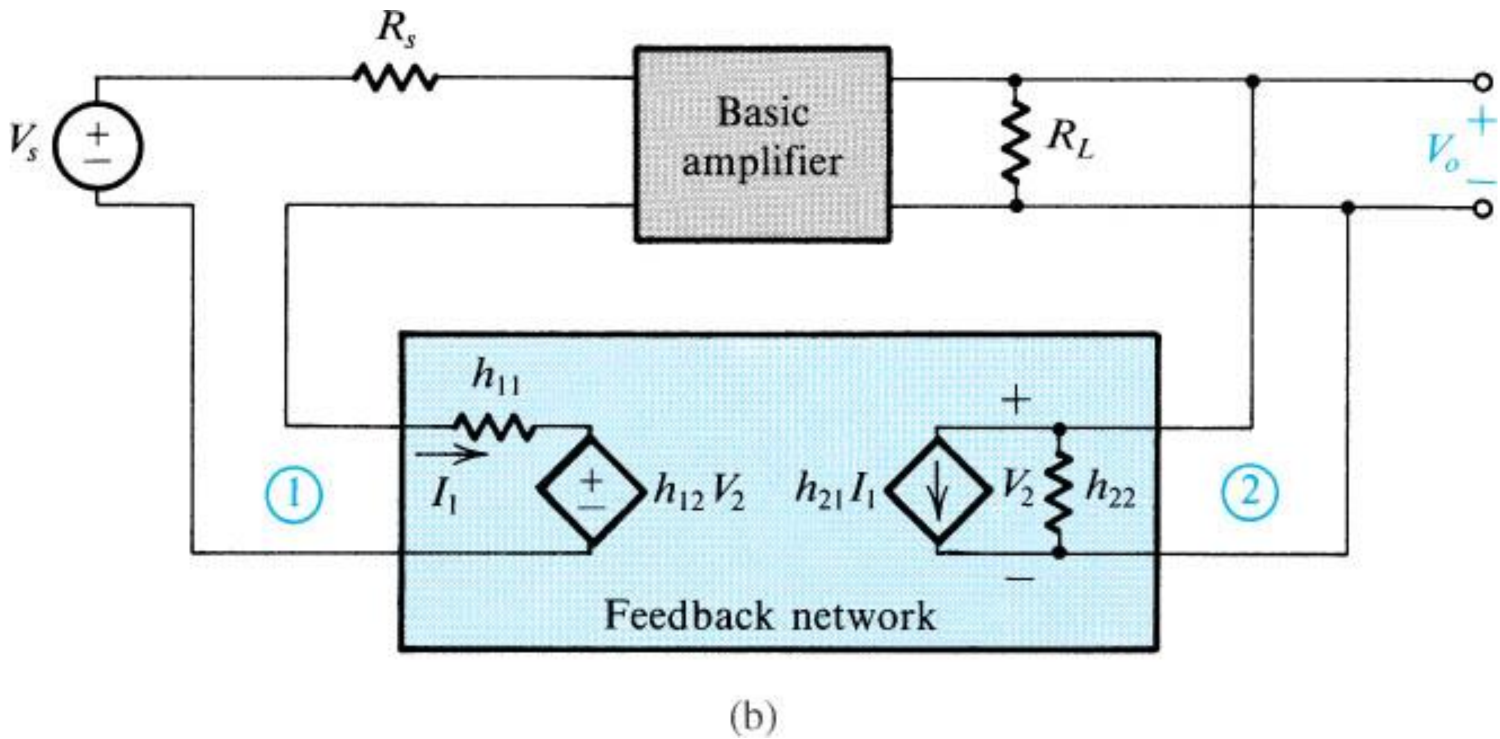


(a)

➢Block diagram of a practical series–shunt feedback amplifier.

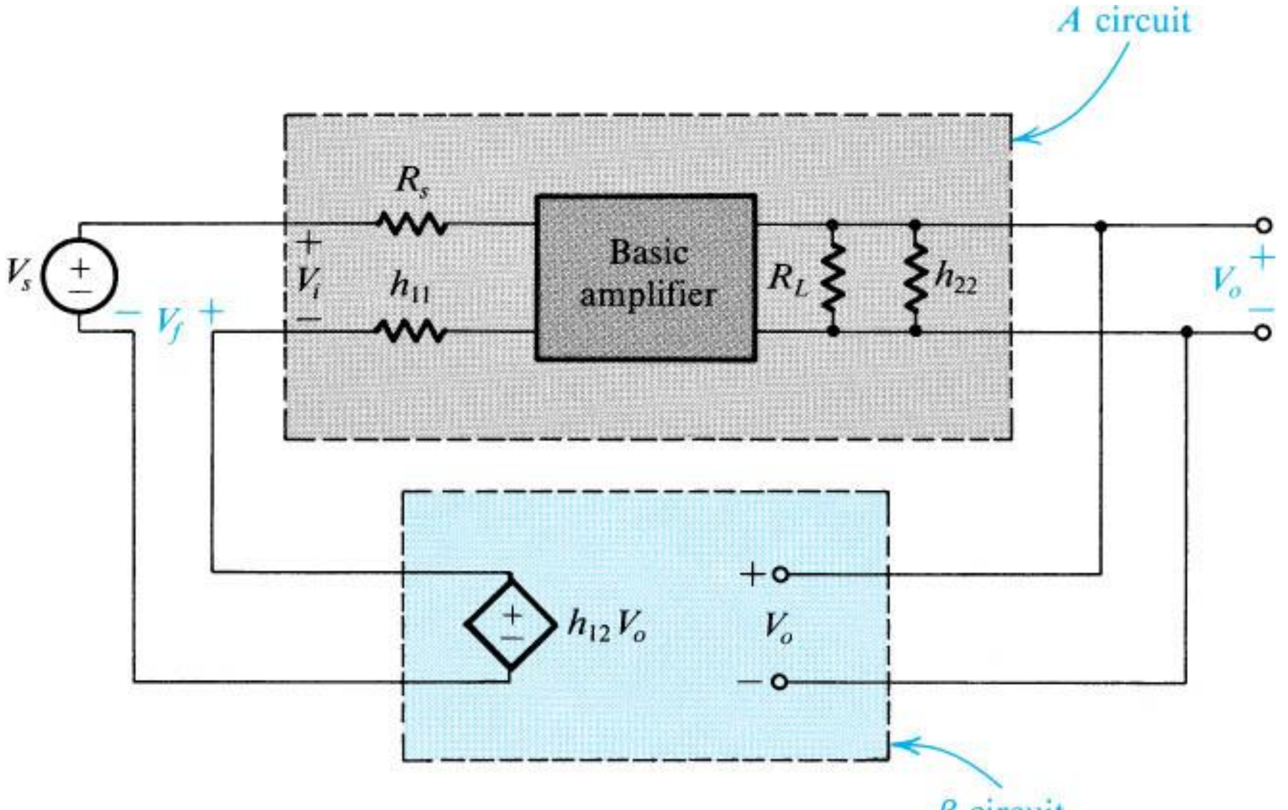
➢Feedback network is not ideal and load the basic amplifier thus affect the values of gain, input resistance and output resistance.

The Practical Situation



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

The Practical Situation



(c)

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

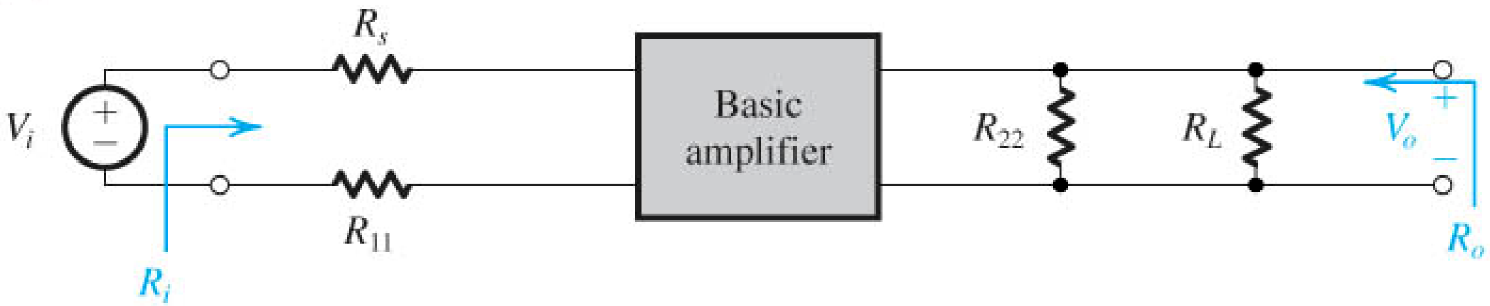
The Practical Situation

- 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.

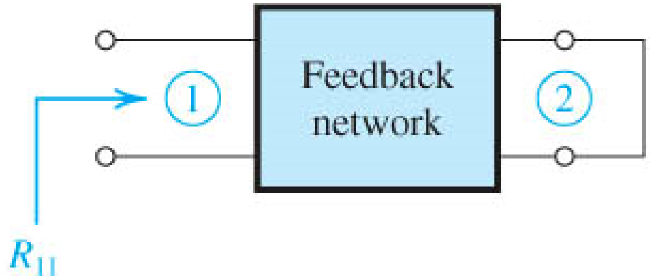
- If the connection is a shunt one, short-circuit the port.
- If the connection is a series one, open-circuit the port.
- Determine the β.

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

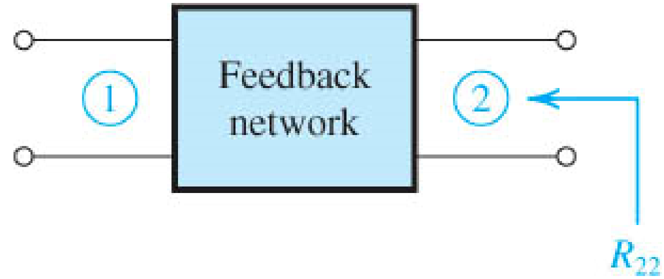
(a) The A circuit is



where R_{11} is obtained from



and R_{22} is obtained from



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

(b) β is obtained from

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

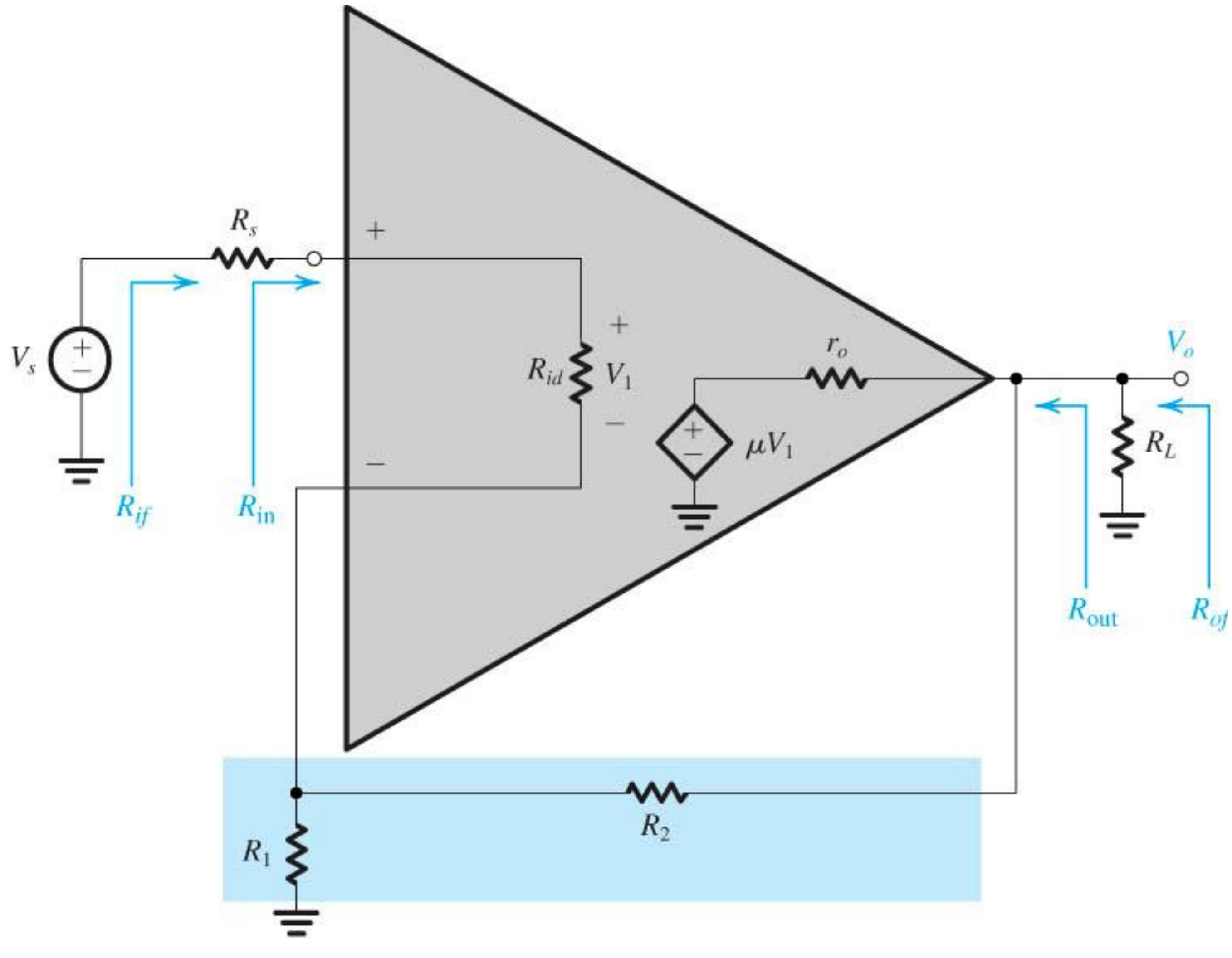
Summary

- 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

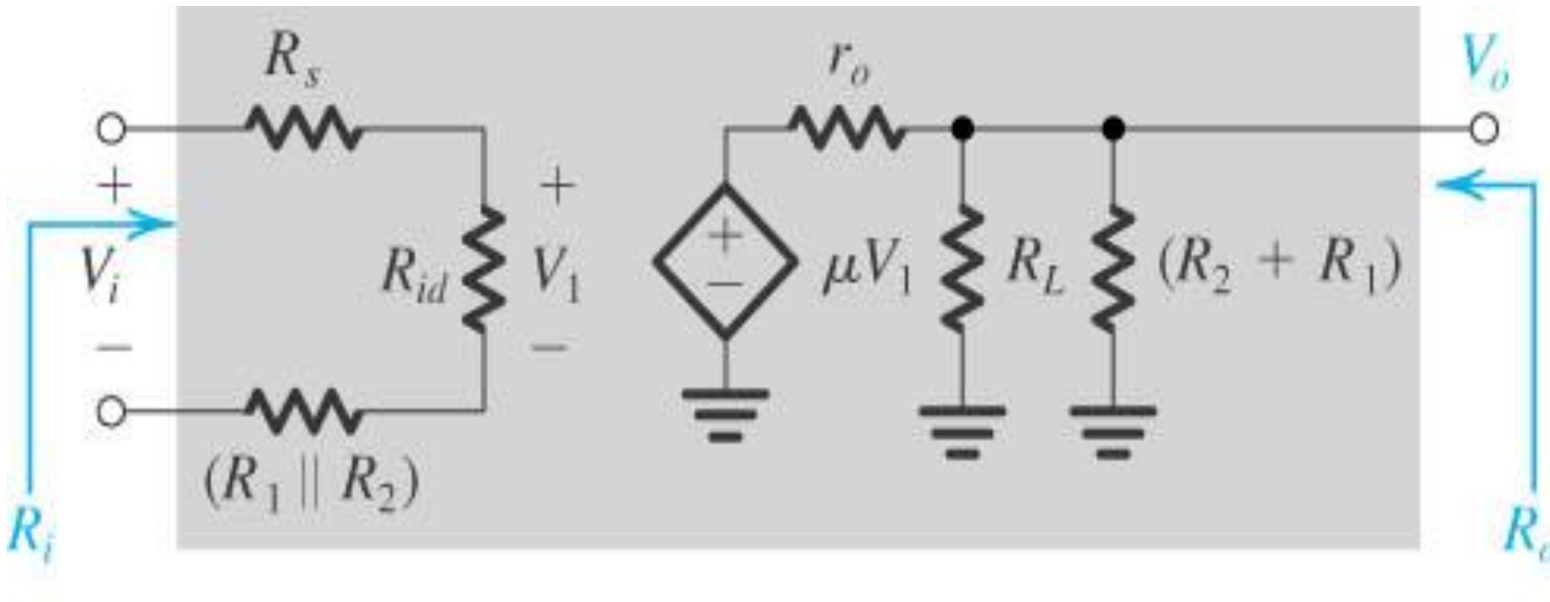


(a)

Example of Series-Shunt Feedback Amplifier

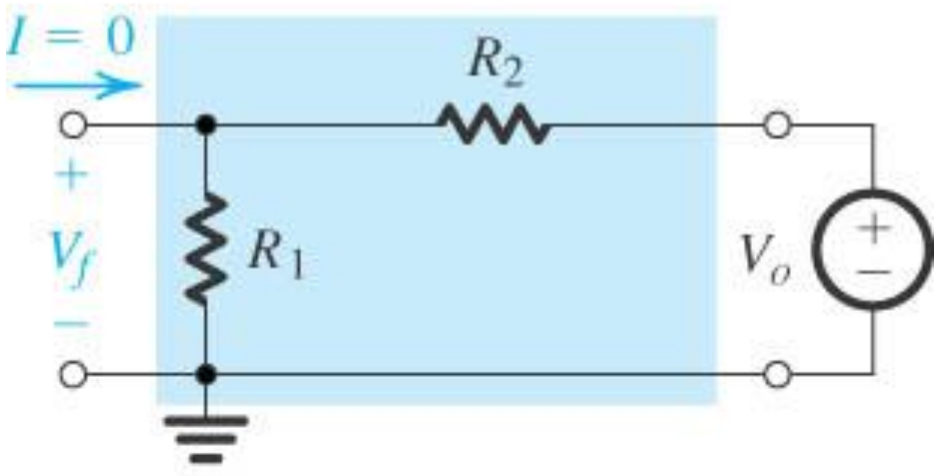
- Op amplifier connected in noninverting configuration with the open-loop gain μ, R_{id} and r_o
- Find expression for A, β, the closed-loop gain V_o/V_i , the input resistance R_{in} and the output resistance R_{out}
- Find numerical values

Example of Series-Shunt Feedback Amplifier



(b)

Example of Series-Shunt Feedback Amplifier



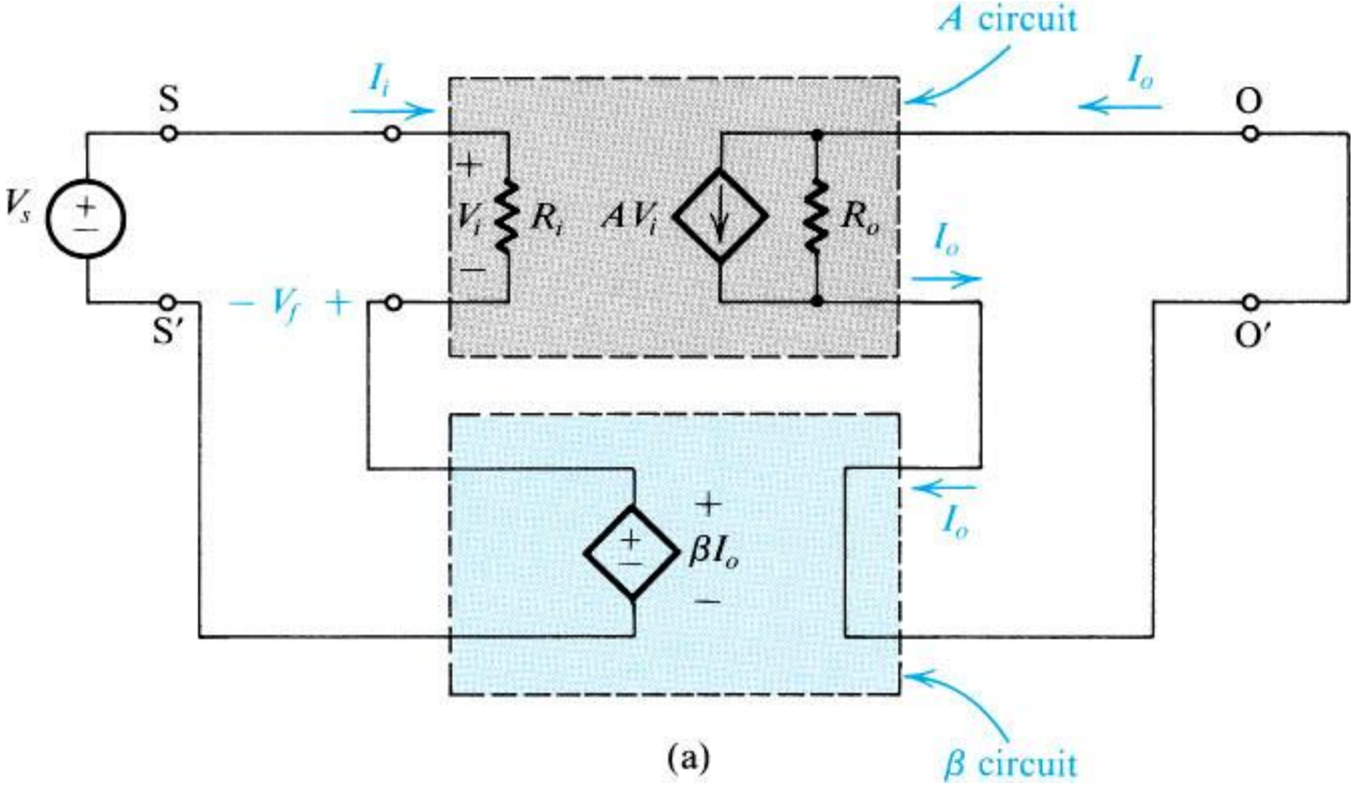
(c)

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

The Series-Series Feedback Amplifier

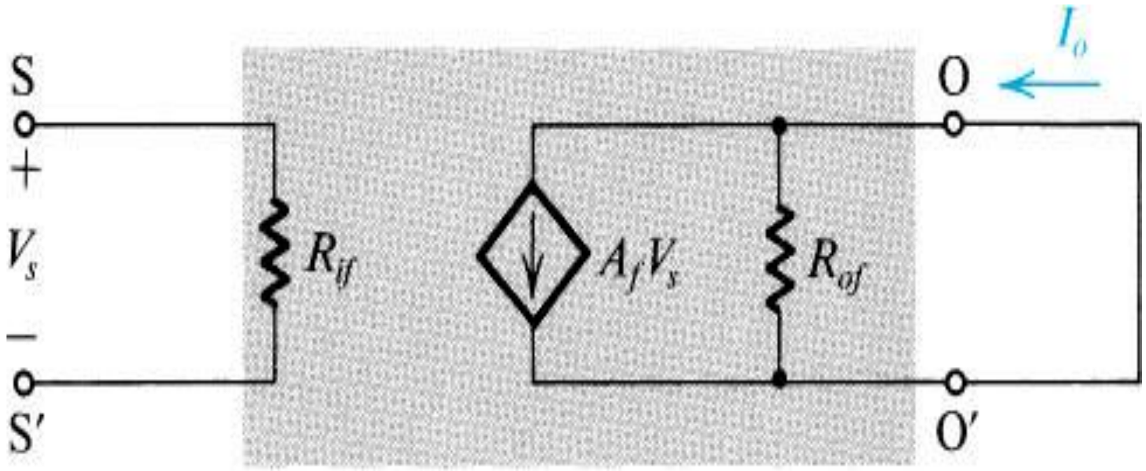
- The ideal situation
- The practical situation
- summary

The Ideal Situation



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

The Ideal Situation



(b)

Tranresistance feedback factor $\beta \equiv \dfrac{V_f}{I_o}$

Input and Output Resistance with Feedback

- Input resistance

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

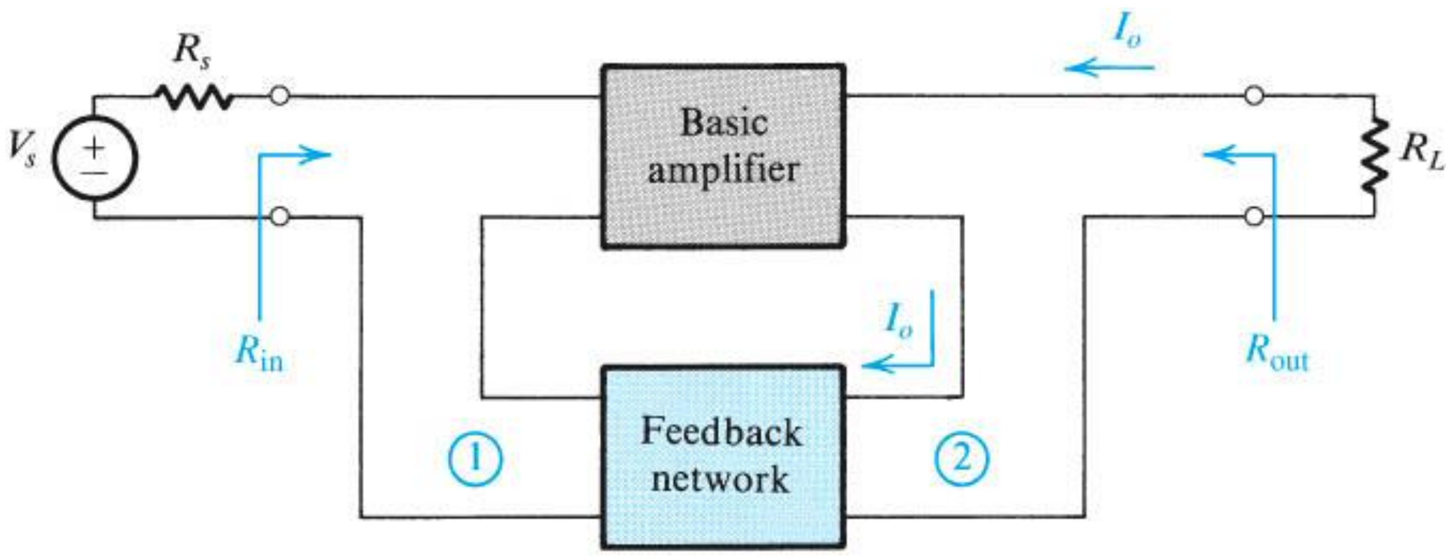
In this case, the negative feedback increases the input resistance by a factor equal to the amount of feedback.

- 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

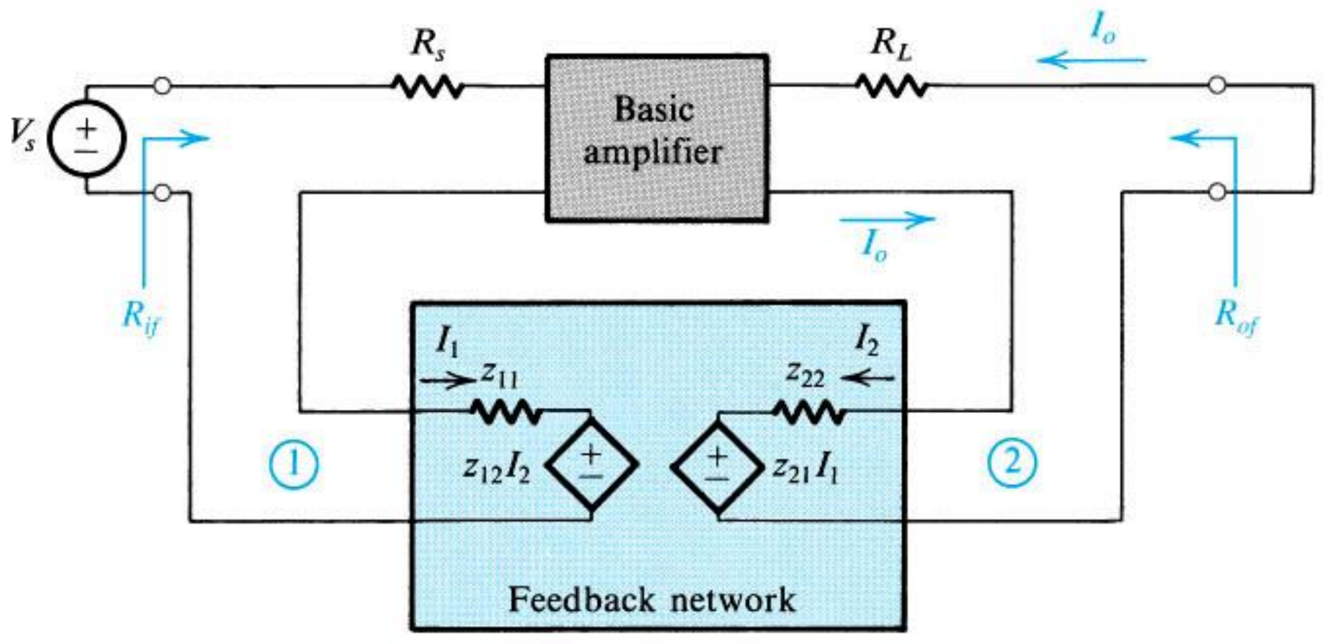


(a)

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.

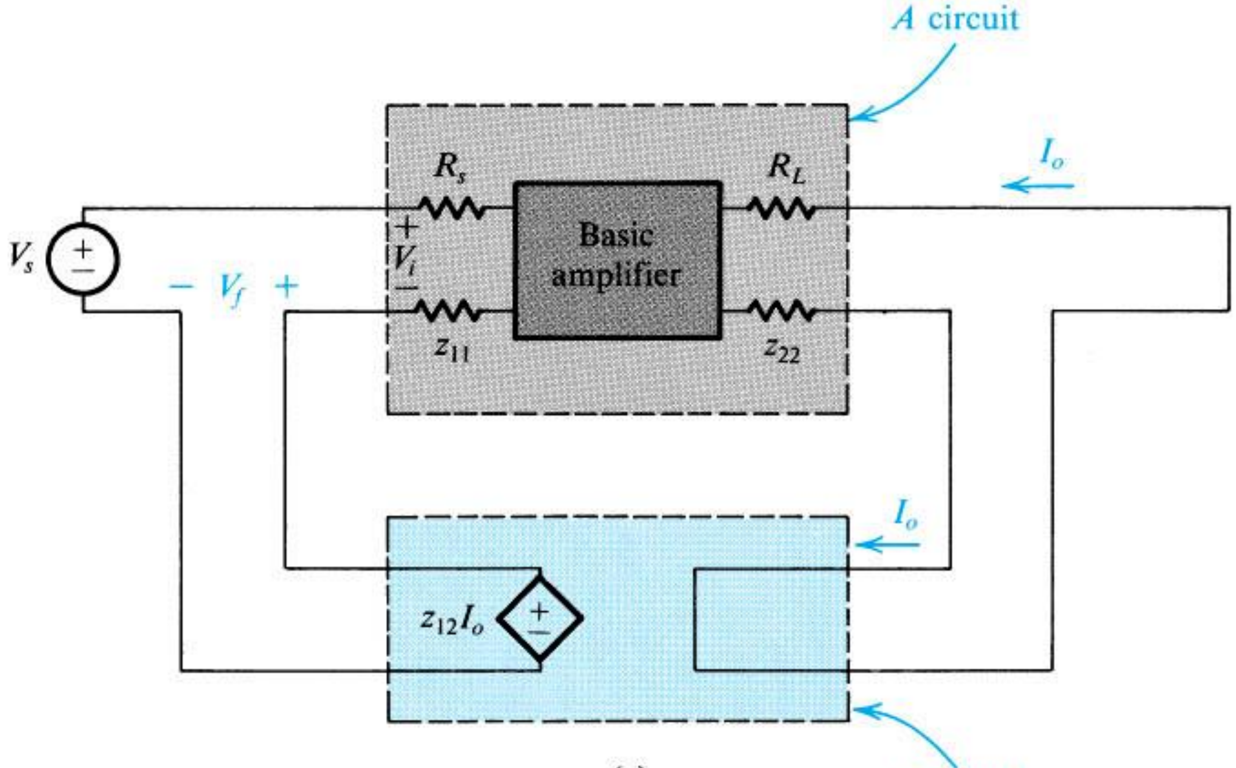
The Practical Situation



(b)

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

The Practical Situation



(c)

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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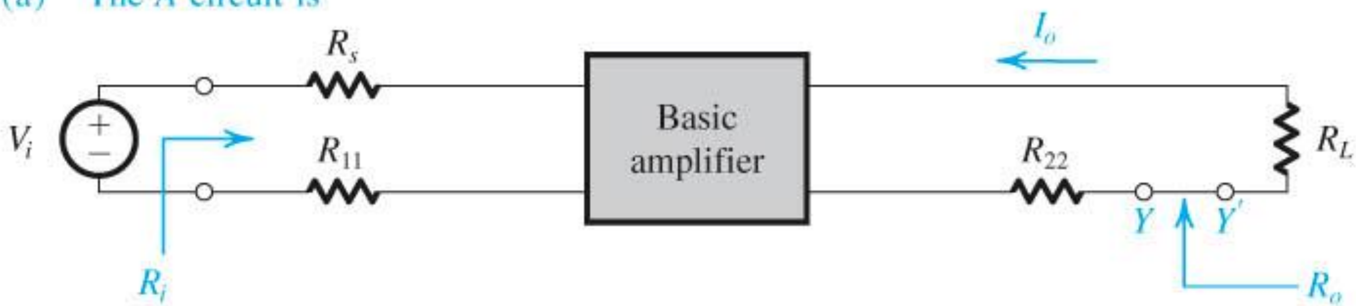

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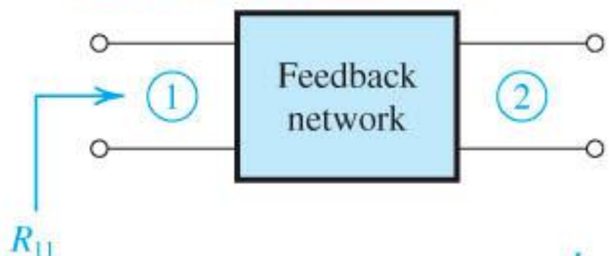
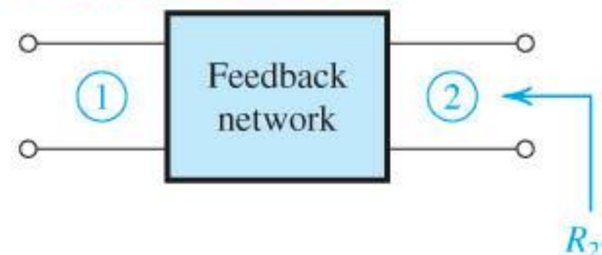
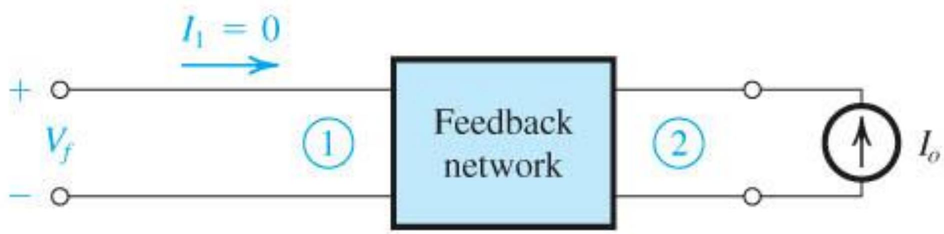


and R_{22} is obtained from



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

(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.
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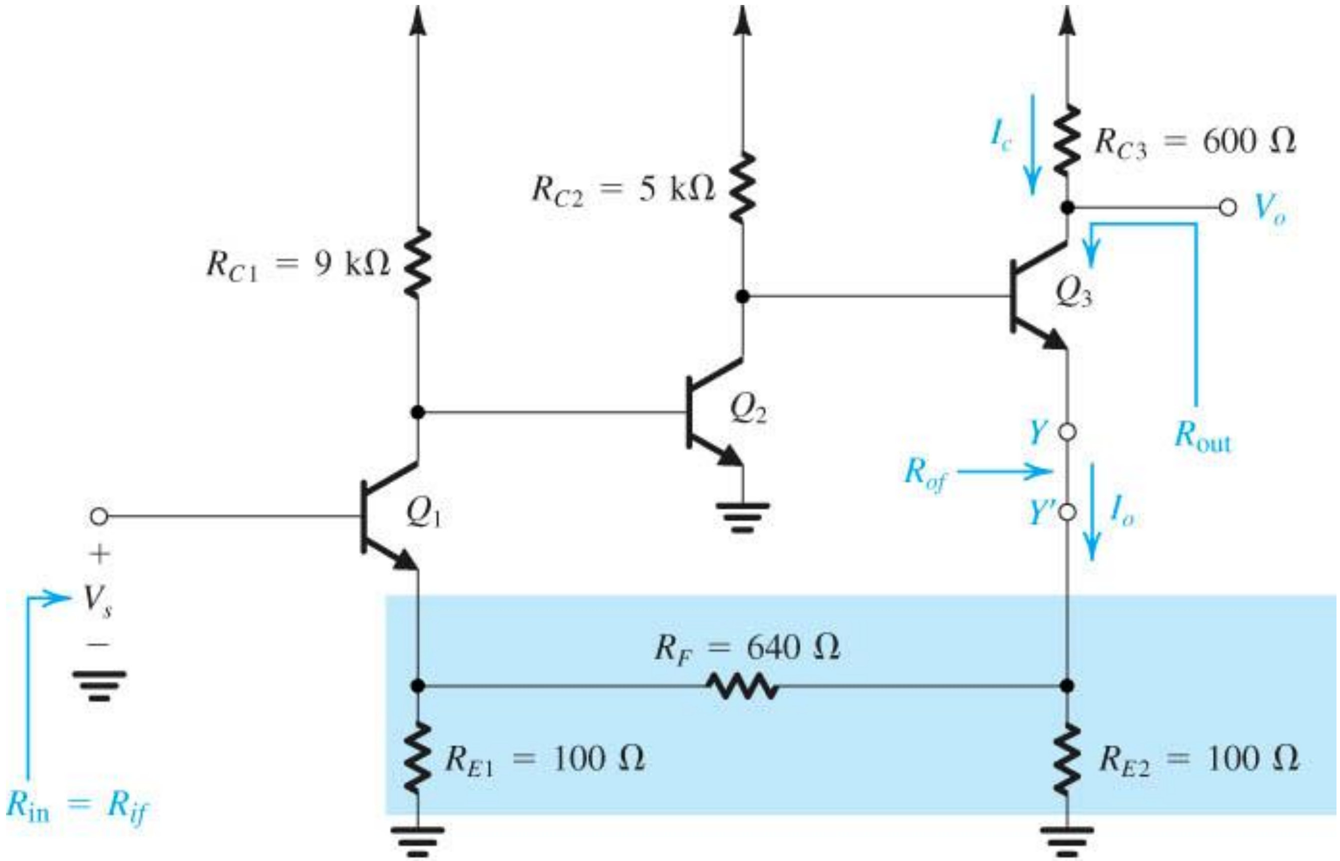
$$R_{if}' = R_{in} + R_s$$

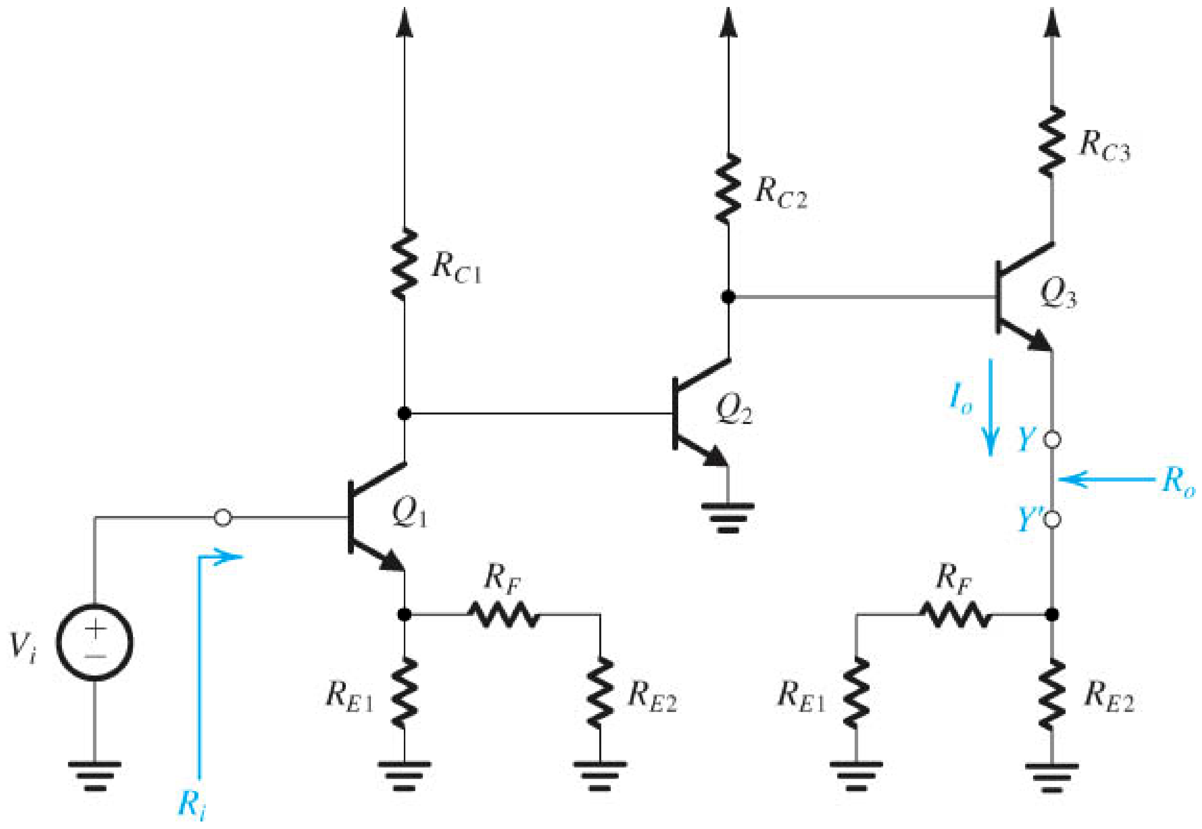
$$R_{of}' = R_{out} + R_L$$

Example of Series-Series Feedback Amplifier



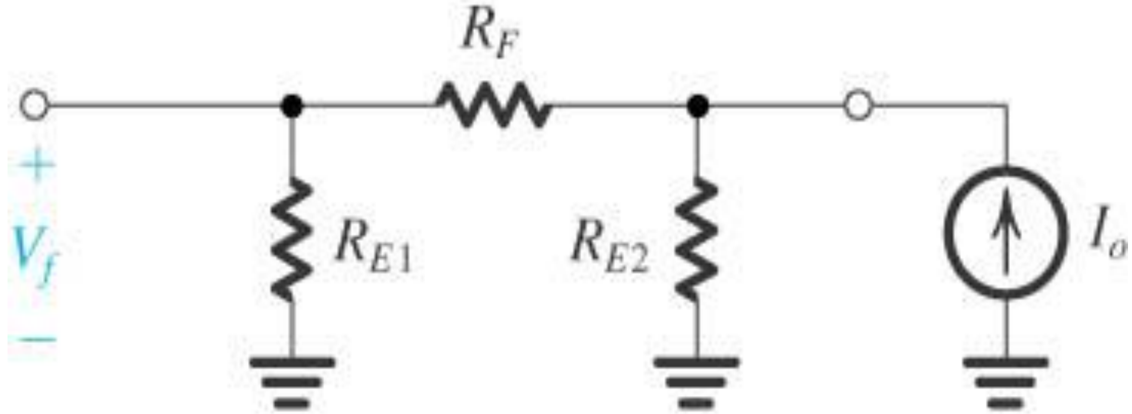
(a)

Example of Series-Series Feedback Amplifier



(b)

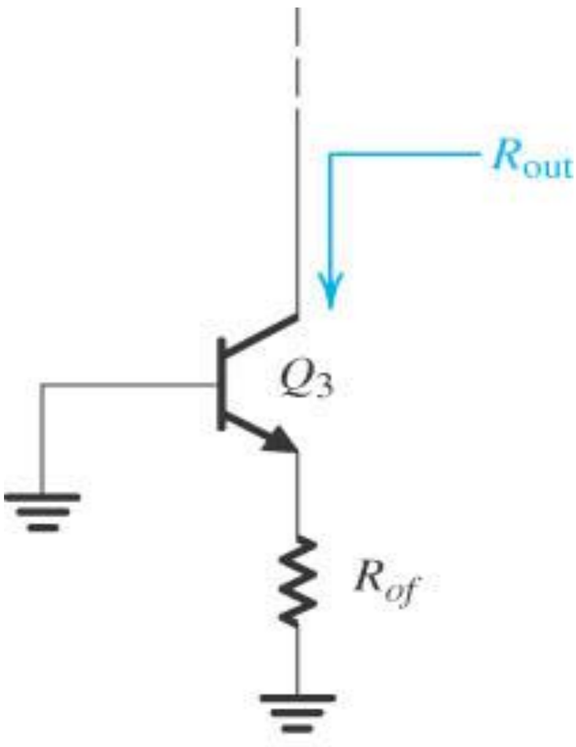
Example of Series-Series Feedback Amplifier



(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



(d)

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

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

$$R_{out} = r_o + (1 + g_{m3} r_o)(R_{of} // r_{\pi 3})$$

The Shunt-Shunt and Shunt-Series Feedback Amplifiers

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

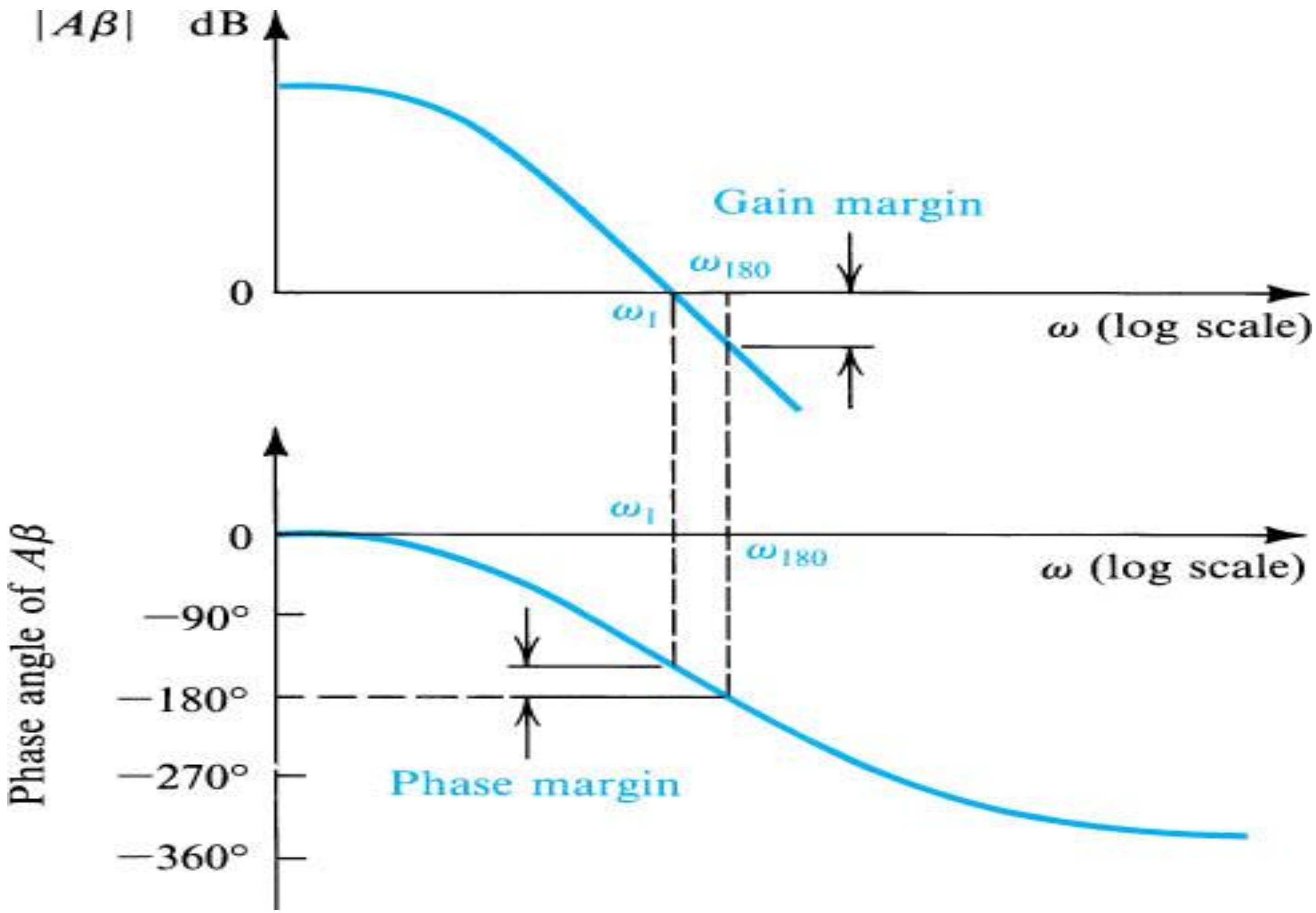
The Stability Problem

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

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

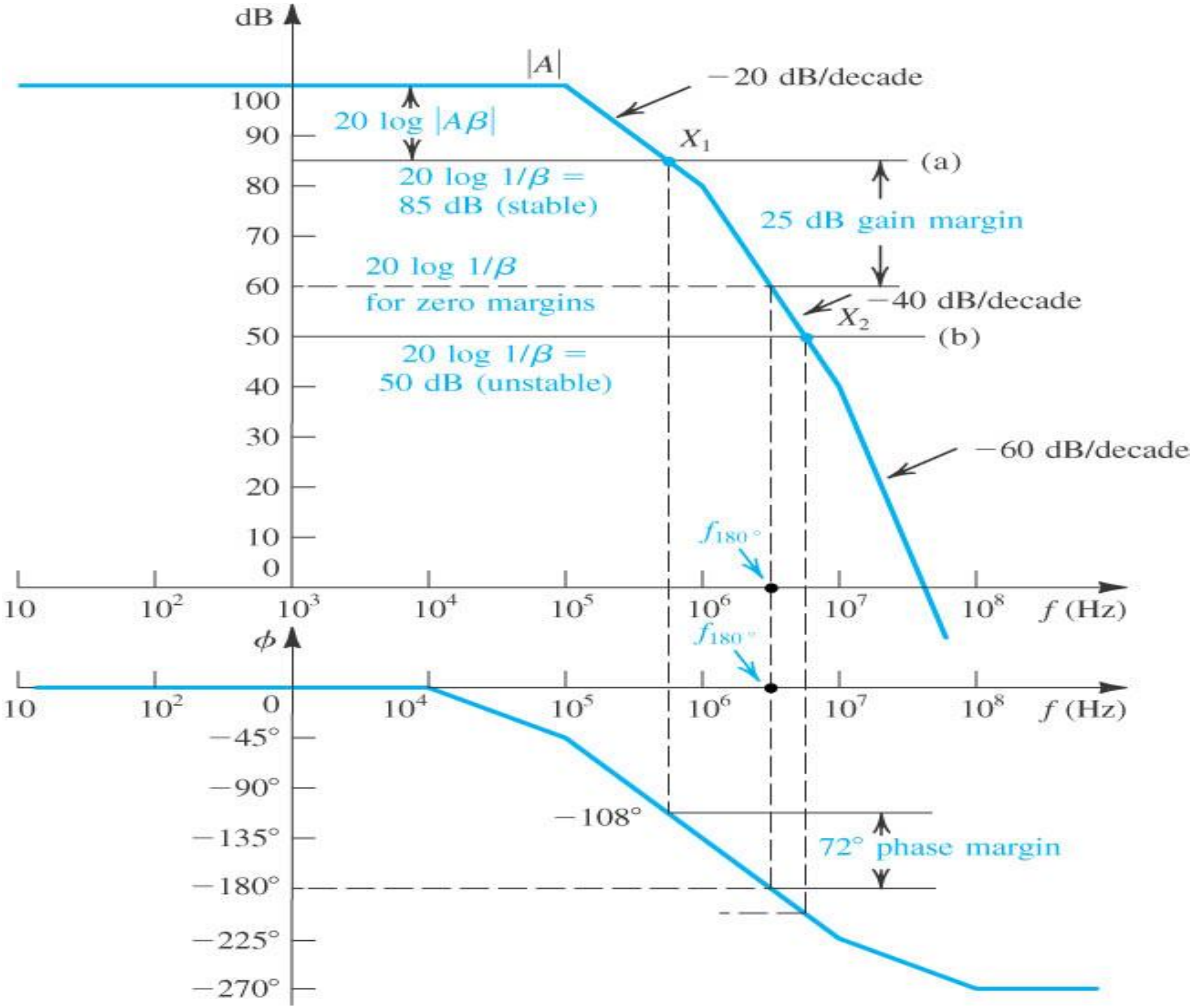
- Any right-half-plane poles results in instability.
  - Amplifier with a single-pole is unconditionally stable.
  - Amplifier with two-pole is also unconditionally stable.
  - Amplifier with more than two poles has the possibility to be unstable.
- Stability study using bode plot

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^{o} 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 20log(1/β) line intersects the 20log|A| curve at a point on the –20dB/decade segment.

- The general rule states:

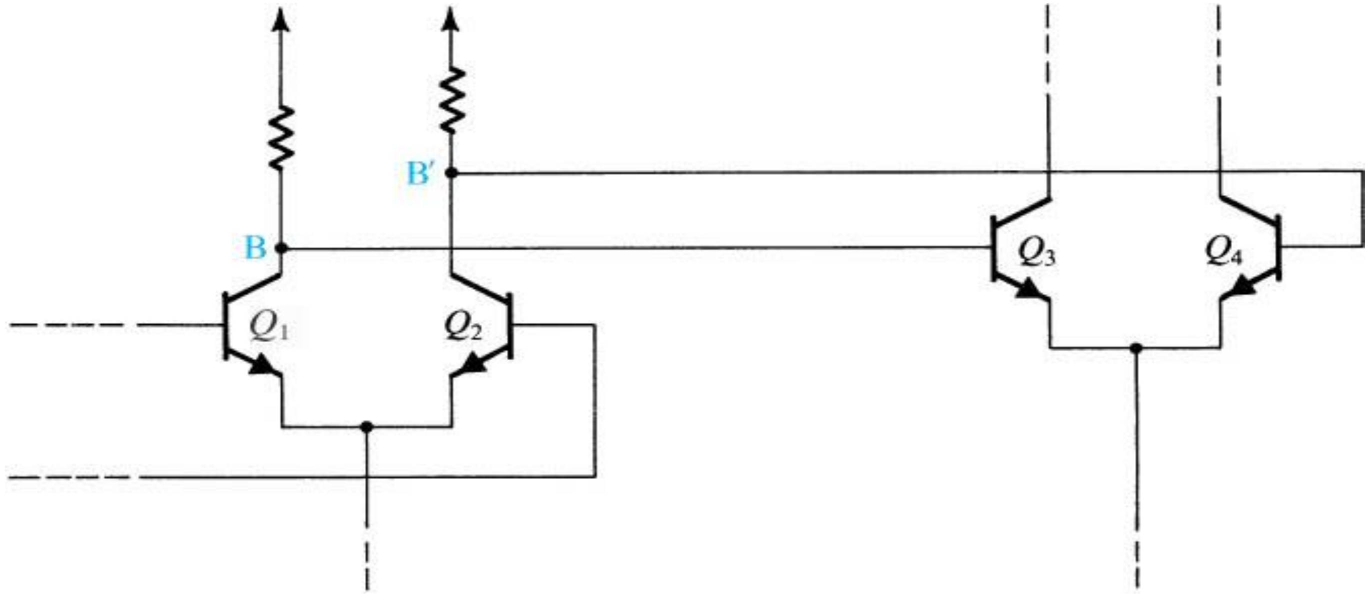
At the intersection of $20\log[1/|\beta(j\omega)|]$ *and* $20\log|A(j\omega)|$ *the difference of slopes should not exceed 20dB/decade.*

Frequency Compensation

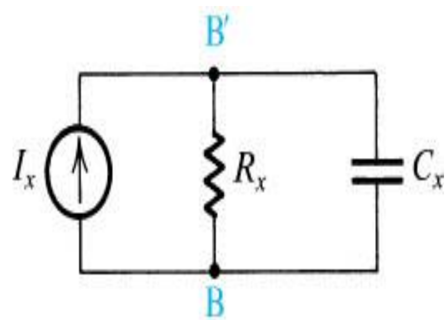
- The purpose is to modifying the open-loop transfer function of an amplifier having three or more poles so that the closed-loop amplifier is stable for any desired value of closed-loop gain.
- Theory of frequency compensation is the enlarge the –20dB/decade line.

- Implementation
  - Capacitance C_c added
  - Miller compensation and pole splitting

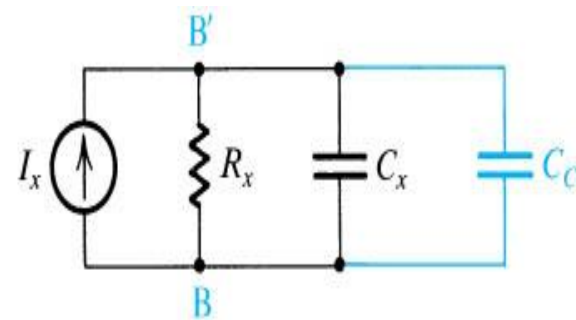
Frequency Compensation



(a)

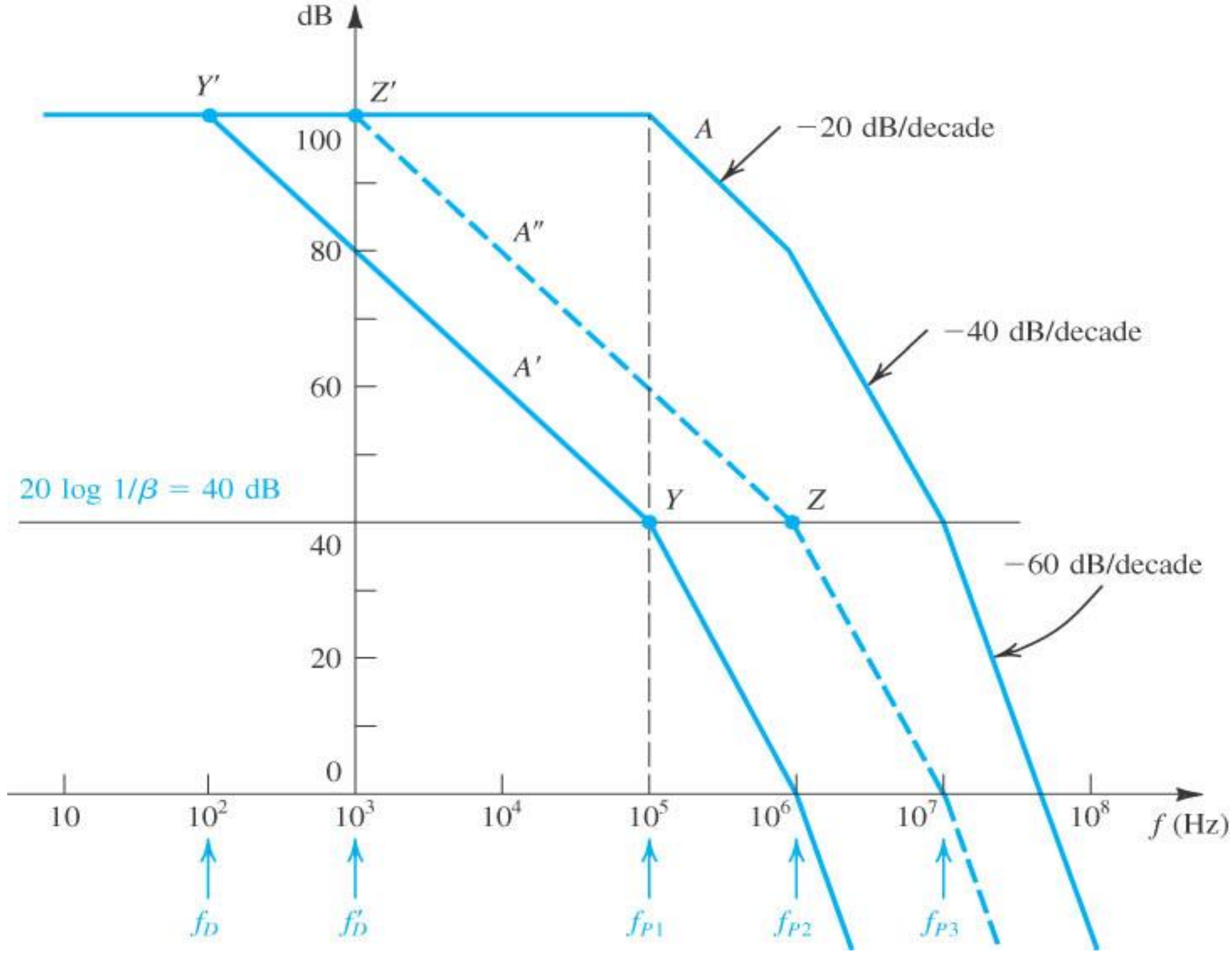


(b)



(c)

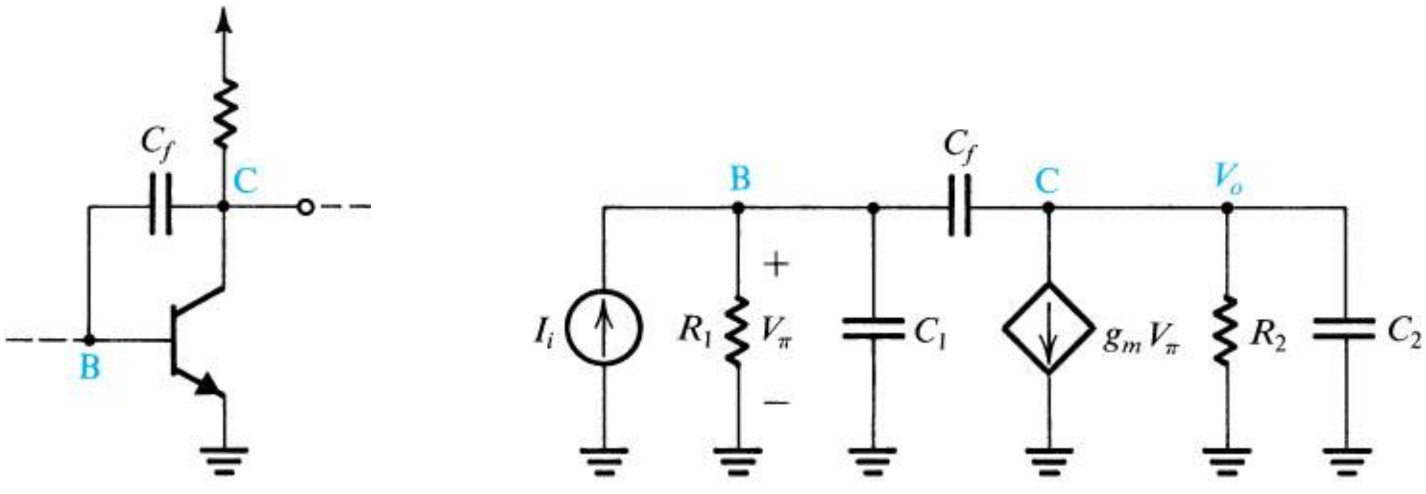
- Two cascaded gain stages of a multistage amplifier.
- Equivalent circuit for the interface between the two stages in (a).
- Same circuit as in (b) but with a compensating capacitor C_C added.



dB
Y′
Z′
100
80
60
40
20
0
A
−20 dB/decade
A″
A′
−40 dB/decade
20 log 1/β = 40 dB
Y
Z
−60 dB/decade
10
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
f (Hz)
f_D
f′_D
f_P1
f_P2
f_P3

- 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) (b)

- ➢A gain stage in a multistage amplifier with a compensating capacitor connected in the feedback path

- ➢An equivalent circuit.