Chapter 13
Feedback Circuits

13.1 Feedback Concepts

Feedback types:

Negative feedback

- **The feedback signal is of opposite polarity to the input signal**
- **Typical application: to improve circuit features**

Positive feedback

- **The feedback signal is of same polarity to the input signal**
- **Typical application: Oscillator circuit**

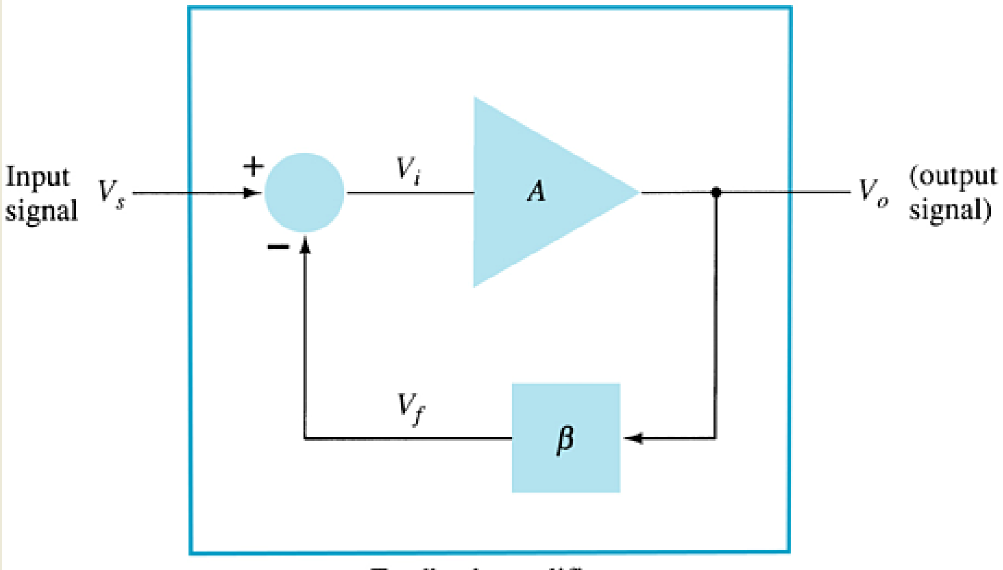
The effects of negative feedback on an amplifier:

Disadvantage

- **Lower gain**

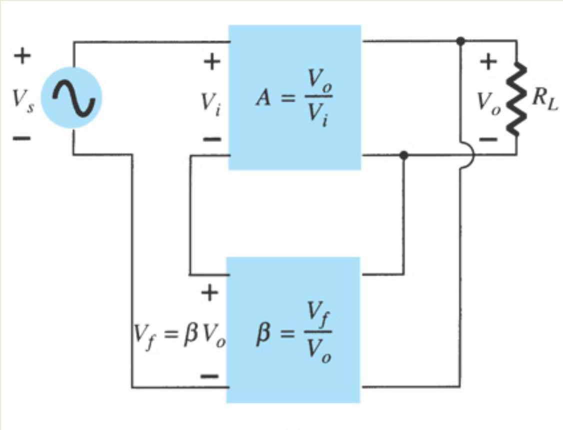
Advantages

- **More stable gain**
- **Reduced noise**
- **More linear operation**

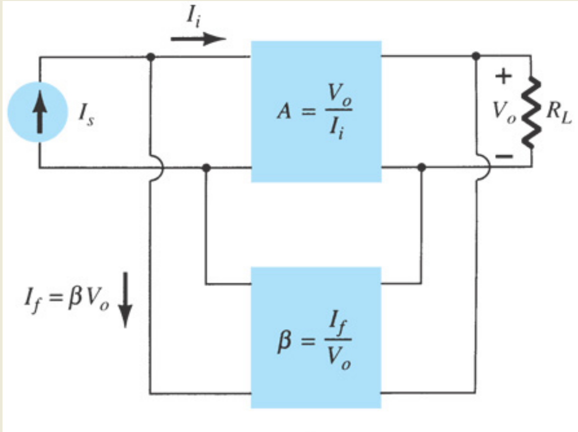


Feedback amplifier

13.2 Feedback Connection Types



(a)



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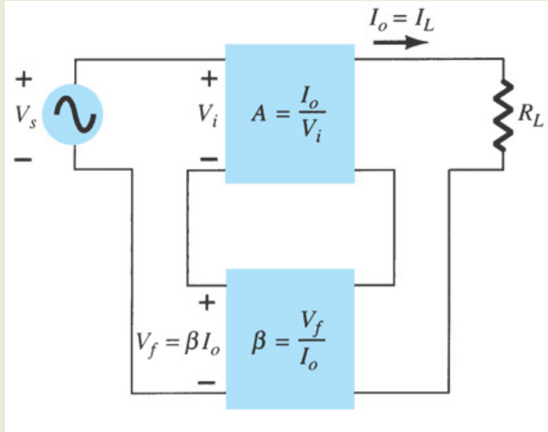

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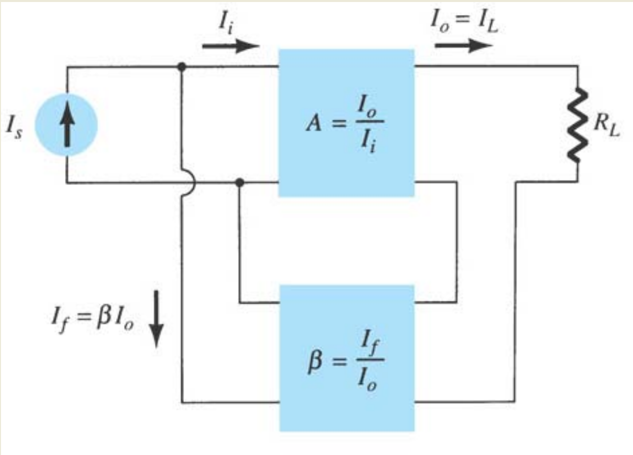


(d)

Summary of Gain, Feedback, and Gain with Feedback

		Voltage-Series	Voltage-Shunt	Current-Series	Current Shunt
Gain without feedback	A	$\frac{V_o}{V_i}$	$\frac{V_o}{I_i}$	$\frac{I_o}{V_i}$	$\frac{I_o}{I_i}$
Feedback	b	$\frac{V_f}{V_o}$	$\frac{I_f}{V_o}$	$\frac{V_f}{I_o}$	$\frac{I_f}{I_o}$
	A_f	$\frac{V_o}{V_s}$	$\frac{V_o}{I_s}$	$\frac{I_o}{V_s}$	$\frac{I_o}{I_s}$

Feedback amplifier types:

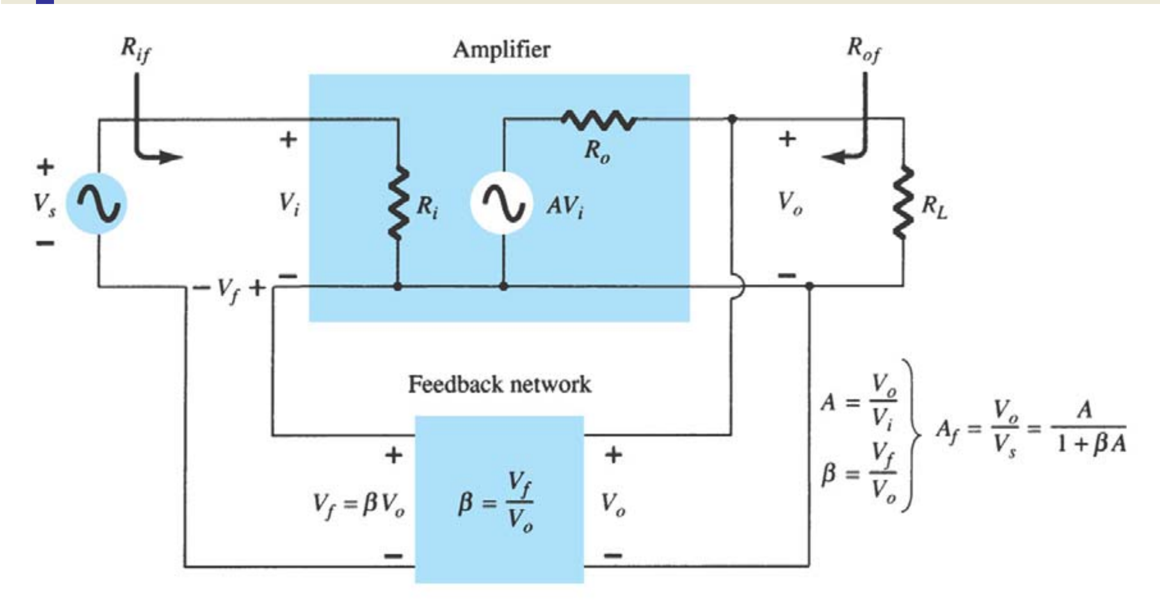
(a) voltage-series feedback, $A_f = V_o / V_s$
(b) voltage-shunt feedback, $A_f = V_o / I_s$
(c) current-series feedback, $A_f = I_o / V_s$
(d) current-shunt feedback, $A_f = I_o / I_s$

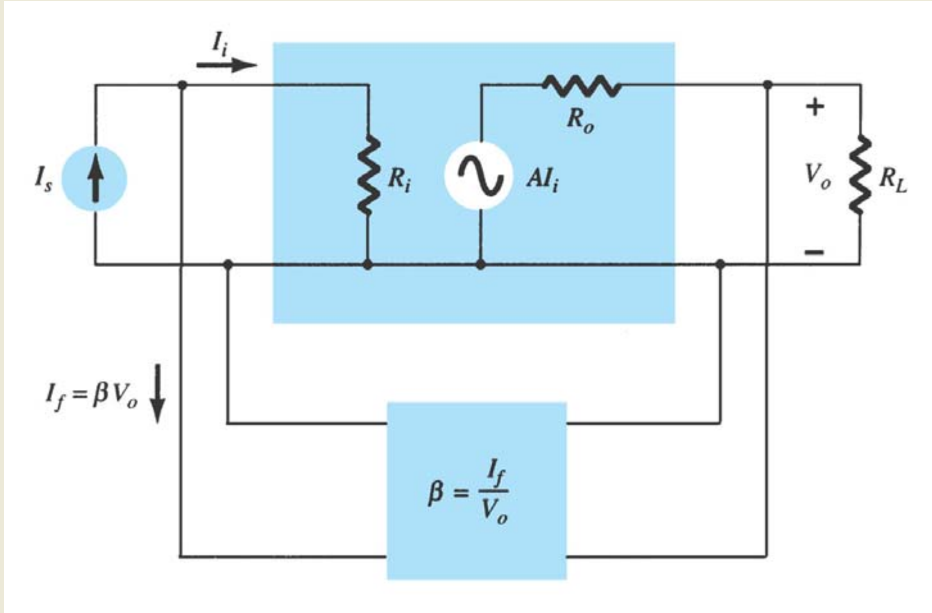
（1）Gain with Feedback:

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

$$A_f \approx \frac{1}{\beta} \quad \text{when } |\beta A| >> 1$$

（2）Input Impedance with Feedback





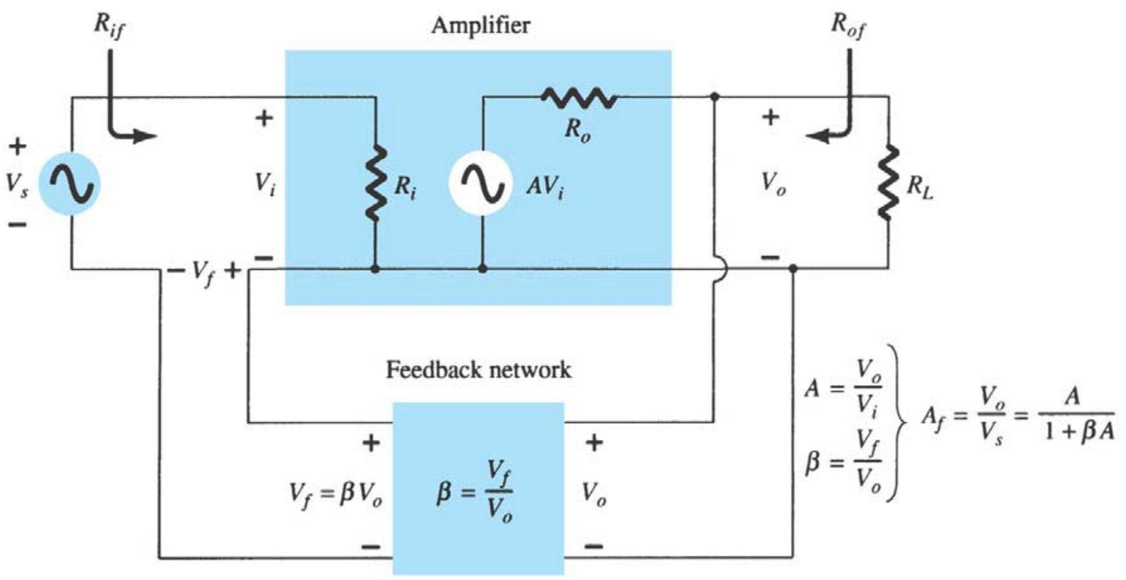
$$Z_{if} = (1+\beta A)Z_i$$

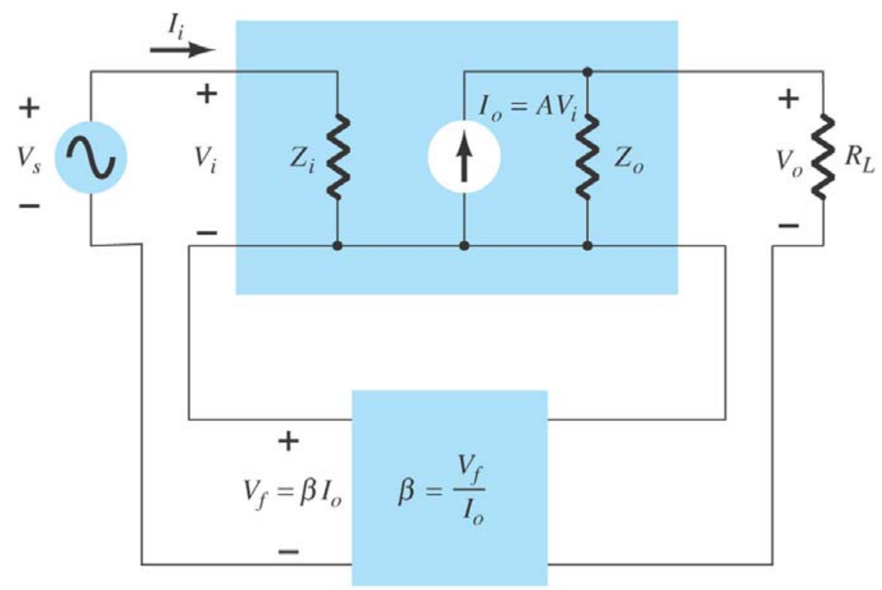
$$Z_{if} = \frac{Z_i}{1+\beta A}$$

Effect of Feedback Connection on Input and Output Impedance

	Voltage-Series	*Current-Series*	*Voltage-Shunt*	*Current-Shunt*
Z_{if}	$Z_i\,(1+\beta A)$ (increased)	$Z_i\,(1+\beta A)$ (increased)	$\frac{Z_i}{1+\beta A}$ (decreased)	$\frac{Z_i}{1+\beta A}$ (decreased)
Z_{of}	$\frac{Z_o}{1+\beta A}$ (decreased)	$Z_o\,(1+\beta A)$ (increased)	$\frac{Z_o}{1+\beta A}$ (decreased)	$Z_o\,(1+\beta A)$ (increased)

（3）Output Impedance with Feedback





$$Z_{of}=\frac{V}{I}=\frac{Z_o}{(1+\beta A)}$$

$$Z_{of}=\frac{V}{I}=(1+\beta A)Z_o$$

Effect of Feedback Connection on Input and Output Impedance

	Voltage-Series	*Current-Series*	*Voltage-Shunt*	*Current-Shunt*
Z_{if}	$Z_i\,(1+\beta A)$ (increased)	$Z_i\,(1+\beta A)$ (increased)	$\frac{Z_i}{1+\beta A}$ (decreased)	$\frac{Z_i}{1+\beta A}$ (decreased)
Z_{of}	$\frac{Z_o}{1+\beta A}$ (decreased)	$Z_o\,(1+\beta A)$ (increased)	$\frac{Z_o}{1+\beta A}$ (decreased)	$Z_o\,(1+\beta A)$ (increased)

(4) Frequency Distortion with Feedback

- If the feedback network is purely resistive, then the gain with feedback will be less dependent on frequency variations.

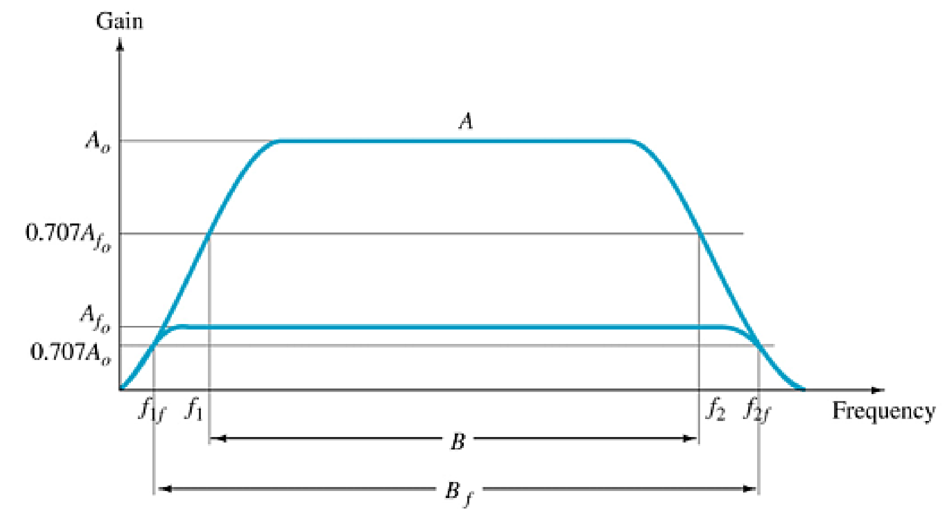
$$A_f \approx \frac{1}{\beta} \quad \text{when } |\beta A| >> 1$$

(5) Noise and Nonlinear Distortion with Feedback

- The feedback network reduces noise by cancellation. The phase of the feedback signal is often opposite the phase of the input signal.
- Nonlinear distortion is also reduced simply because the gain is reduced. The amplifier is operating in midrange and not at the extremes.

(6) Bandwidth with Feedback

Feedback increases the bandwidth of an amplifier. The gain-bandwidth product remains the same.



(7) Gain Stability with Feedback

Gain calculations with feedback are often based on external resistive elements in the circuit. By removing gain calculations from internal variations of β and g_m, the gain becomes more stable.

$$A_f \approx \frac{1}{\beta} \quad \text{when } |\beta A| >> 1$$

Summary of Negative Feedback Effects

- Gain
  - Reduced gain, but improve gain stability $A_f = \dfrac{A}{1+\beta A}$
- Input impedance
  - **- series: increase input impedance $Z_{if} = (1+\beta A)Z_i$
  - **-shunt: decrease input impedance $Z_{if} = \dfrac{Z_i}{1+\beta A}$
- Output impedance
  - voltage-**: decrease output impedance $Z_{of} = \dfrac{Z_o}{(1+\beta A)}$
  - current-**: increase output impedance $Z_{of} = (1+\beta A)Z_o$
- Reduced noise
- More linear operation
- Improve frequency response and increase bandwidth $B_f = (1+\beta A)B$

when $|\beta A| >> 1$

$$A_f \approx \frac{1}{\beta}$$

$$Z_{if} = \infty$$

$$Z_{if} = 0$$

$$Z_{of} = 0$$

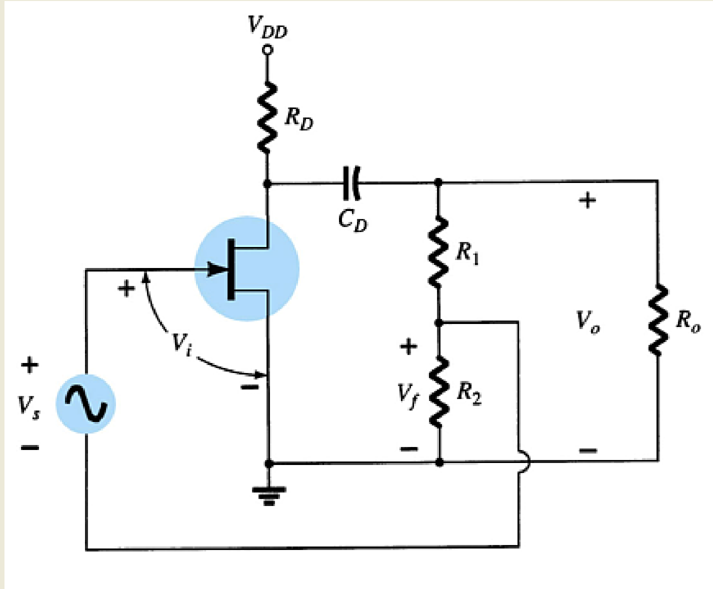
$$Z_{of} = \infty$$

when $|\beta A| >> 1$

Determine the feedback type → **Determine the feedback** β → **Determine the feedback gain** $A_f \approx 1/\beta$ → **Determine other unknowns** A_{vf}, Z_{if}, Z_{of}

13.3 Practical Feedback Circuits

(a) Voltage-Series Feedback



Open loop: $A = -g_m(R_D \parallel R_o \parallel (R_1 + R_2))$

$$\beta = \frac{V_f}{V_o} = \frac{R_2}{R_1 + R_2}$$

close loop: $A_{vf} = A_f = \dfrac{A}{1 + \beta A}$

If $|\beta A| >> 1$ $\quad A_{vf} = A_f \cong \dfrac{1}{\beta} = \dfrac{R_1 + R_2}{R_2}$

(b) Voltage-Shunt Feedback

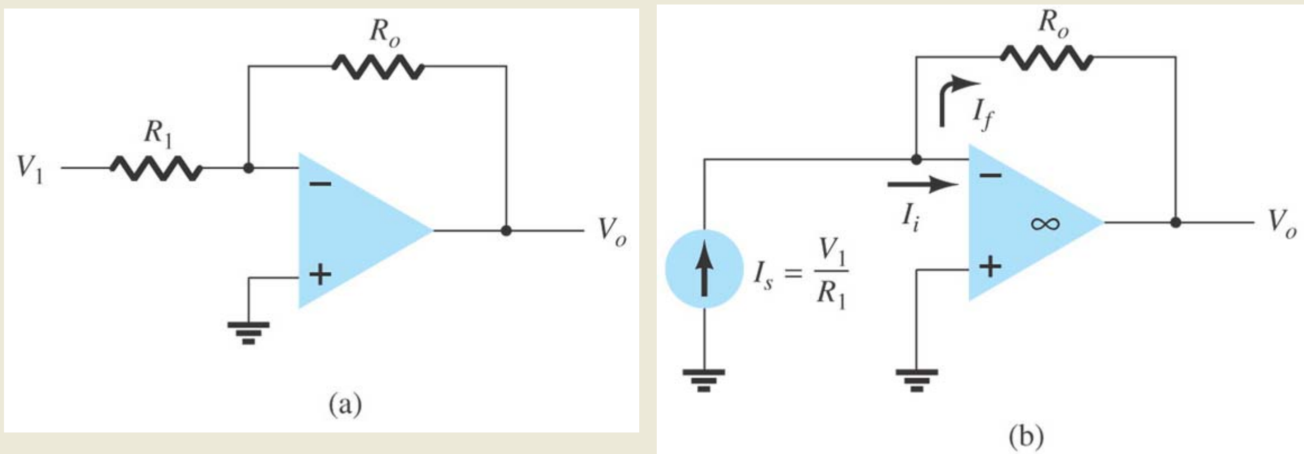
For a voltage-shunt feedback amplifier, the output voltage is fed back in parallel with the input.

$|\beta A| >> 1$

$$\beta = \frac{I_f}{V_o} = -\frac{1}{R_o}$$

$$A_f = \frac{V_o}{I_s} \cong \frac{1}{\beta} = -R_o$$

$$A_{vf} = \frac{V_o}{V_i} = \frac{V_o}{I_s R_i} = -\frac{R_o}{R_i}$$



(c) Current-Series Feedback

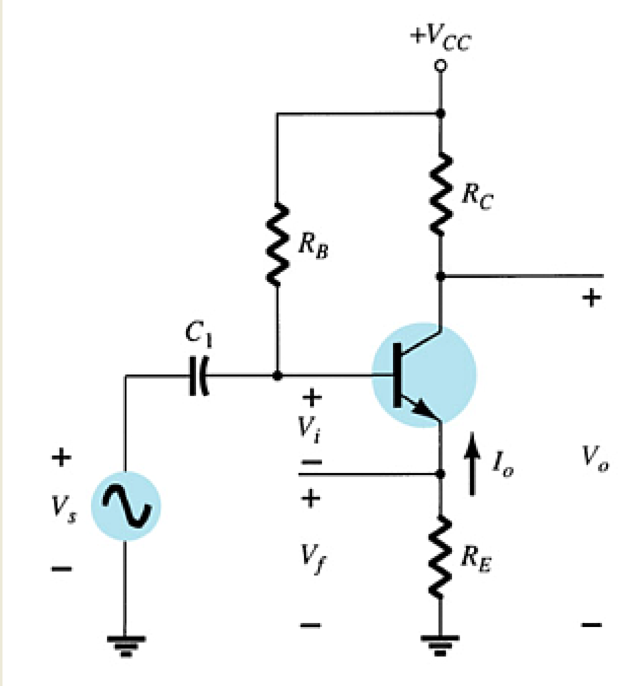
Open loop: $A = \dfrac{I_o}{V_i} = -\dfrac{h_{fe}}{h_{ie} + R_E}$ $Z_i = R_B \parallel Z_{ib} = R_B \parallel (h_{ie} + R_E)$

$Z_o = R_C$ $\beta = \dfrac{V_f}{I_o} = -R_E$

close loop: $A_f = \dfrac{I_o}{V_s} = \dfrac{\text{A}}{1 + \beta\text{A}}$ $A_{vf} = \dfrac{I_o R_C}{V_s} = R_C A_f$

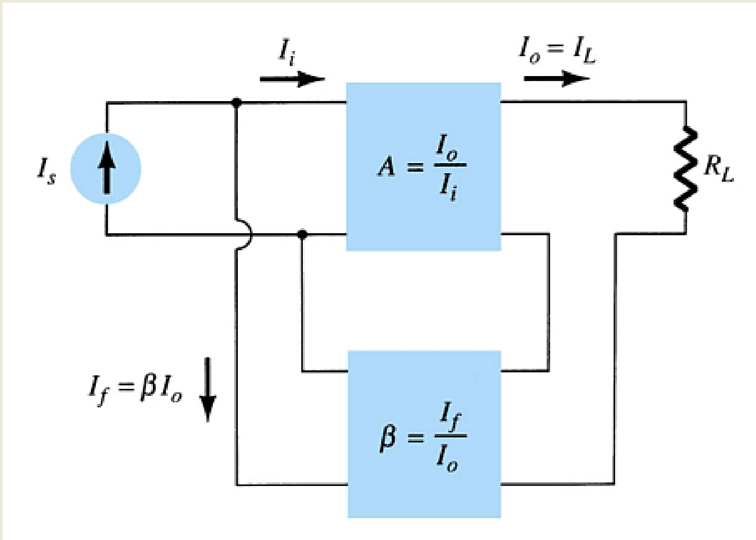
$Z_{if} = R_B \parallel (1 + \beta A) Z_{ib}$ $Z_{of} = (1 + \beta A) R_C$

If $|\beta A| >> 1$ $A_f = \dfrac{I_o}{V_s} \cong \dfrac{1}{\beta} = -\dfrac{1}{R_E}$ $A_{vf} = \dfrac{I_o R_C}{V_s} = -\dfrac{R_C}{R_E}$



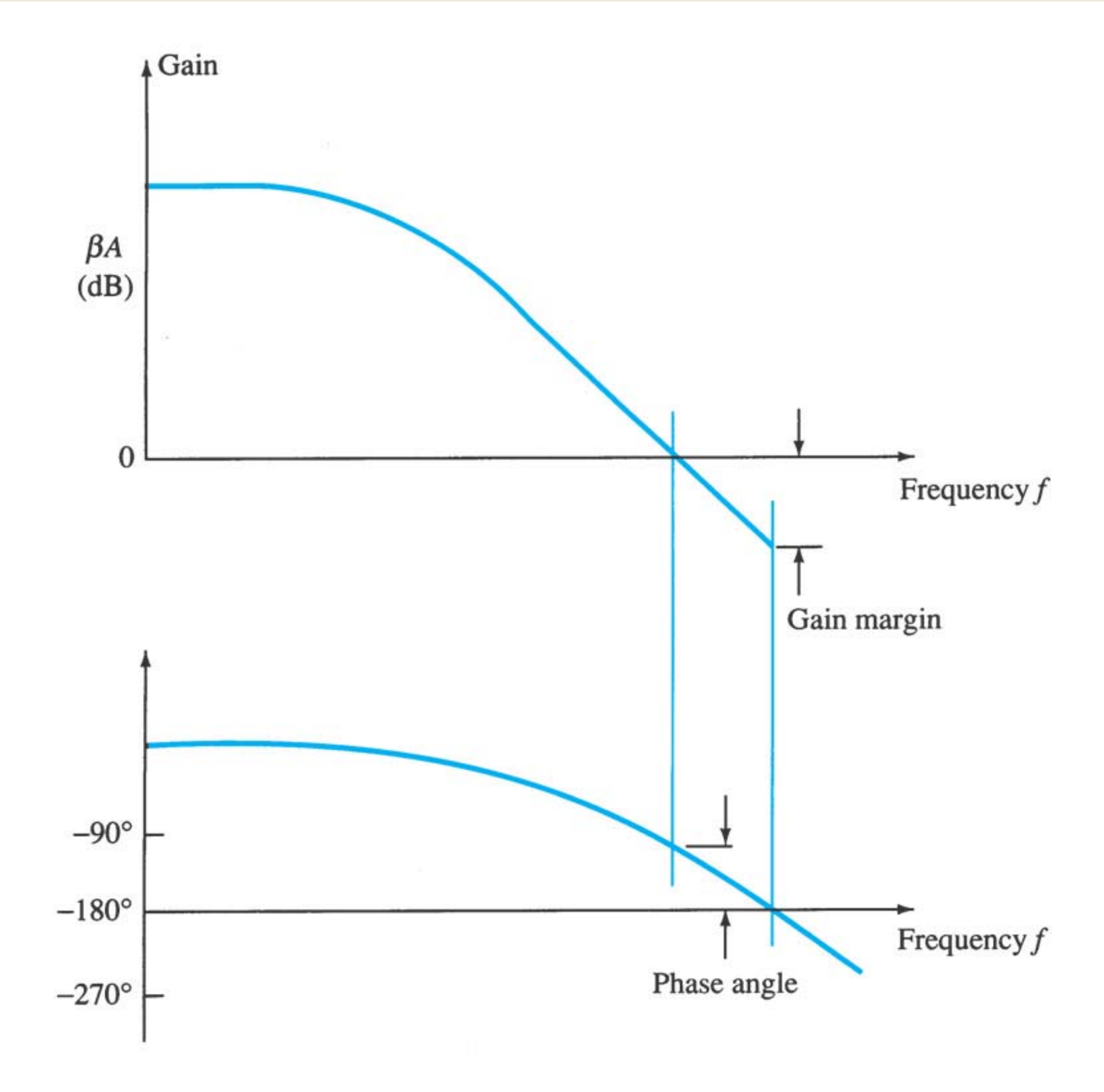
(d) Current-Shunt Feedback

The feedback gain is given by: $\mathbf{A_f = \dfrac{I_o}{I_s}}$



13.4 Feedback Amplifier-phase and frequency considerations

Gain and Phase Margins



Gain margin (GM)

is defined as the negative of the value of $|\beta A|$ in decibels at the frequency at which the phase angle is 180° .

Phase margin (PM)

is defined as the angle of 180° minus the magnitude of the angle at which the value $|\beta A|$ is unity (0dB)

Summary of Chapter 13

Feedback concepts and types of negative feedback

- Find out feedback and determine the type of feedback

Effects of negative feedback

when $|\beta A| >> 1$

- Gain
  - Reduced gain, but improve gain stability $A_f = \dfrac{A}{1+\beta A}$ $\quad A_f \approx \dfrac{1}{\beta}$
- Input impedance
  - **- series: increase input impedance $Z_{if} = (1+\beta A)Z_i$ $\quad Z_{if} = \infty$
  - **-shunt: decrease input impedance $Z_{if} = \dfrac{Z_i}{1+\beta A}$ $\quad Z_{if} = 0$
- Output impedance
  - voltage-**: decrease output impedance $Z_{of} = \dfrac{Z_o}{(1+\beta A)}$ $\quad Z_{of} = 0$
  - current-**: increase output impedance $Z_{of} = (1+\beta A)Z_o$ $\quad Z_{of} = \infty$
- Reduced noise
- More linear operation
- Improve frequency response and increase bandwidth $B_f = (1+\beta A)B$

Gain and phase margin —— stable of a negative feedback amplifier

- To determine whether a negative feedback amplifier is stable.