第十二章 回授與穩定度

- 回授的觀念
- 理想回授系統
- 四個理想回授電路之組態
  - 串-並(電壓)回授放大器
  - 並-串(電流)回授放大器
  - 串-串(轉移電導)回授放大器
  - 並-並(轉移電阻)回授放大器
- 回授電路之迴路增益
- 回授電路之穩定性準則
- 頻率補償技術

（藉由補償使得不穩定之回授電路能穩定）

第十二章 回授與穩定度

12.1 回授的觀念

<u>兩種回授</u>

正回授－輸入信號加上部份的輸出信號

負回授－輸入信號減掉部份的輸出信號

<u>負回授的優點</u>

1）減少增益的敏感度

2）擴增電路的頻寬

3）減少雜訊的敏感度

4）減少非線性失真

5）控制電路的輸入/出阻抗

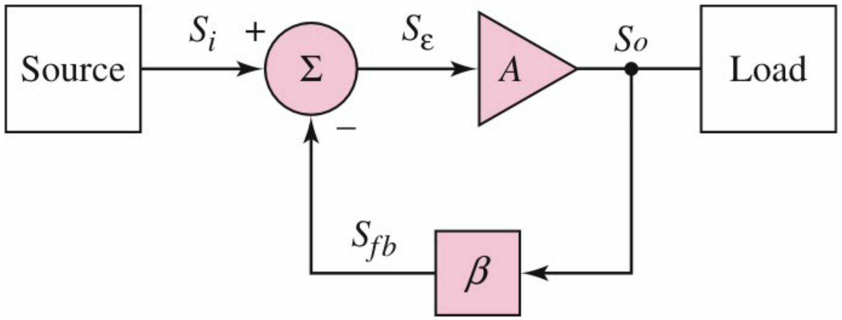
<u>負回授的缺點</u>

1）減少電路的增益

2）減少電路的穩定性

第十二章 回授與穩定度

12.2 理想回授系統



$$S_o = AS_\varepsilon ; S_{fb} = \beta S_o ; S_\varepsilon = S_i - S_{fb}$$

$$S_0 = A(S_i - \beta S_0) = AS_i - A\beta S_0$$

$$A_f = \frac{S_0}{S_i} = \frac{A}{1+A\beta} = \frac{A}{1+T}$$

A ：開迴路增益(open-loop gain)

β ：回授因子(feedback factor)

A_f ：閉迴路增益(closed-loop gain)

T ＝ βA 為迴路增益(loop gain)

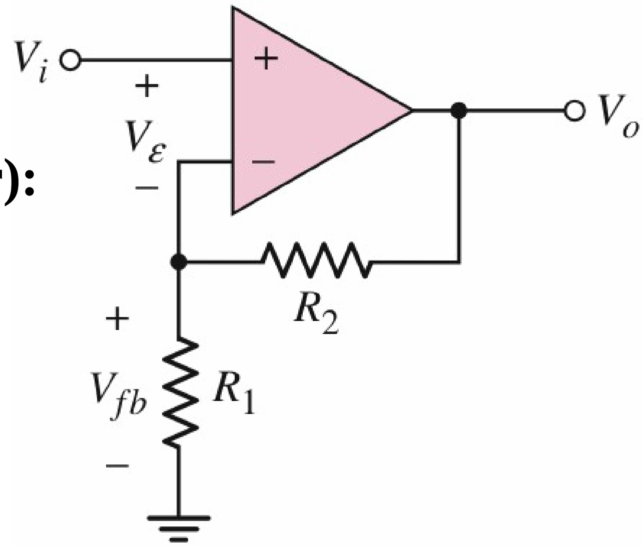
$$T = A\beta = \frac{S_{fb}}{S_\varepsilon}$$

$$A\beta \succ\succ 1 \rightarrow A_f \cong \frac{A}{A\beta} = \frac{1}{\beta}$$

非反相放大器(Non-inverting amplifier):

$$V_{fb} = \frac{R_1}{R_1 + R_2} V_o \qquad \rightarrow \qquad \beta = \frac{R_1}{R_1 + R_2}$$

$$If \qquad A\beta >> 1, \qquad A_f = \frac{V_o}{V_i} = \frac{1}{\beta} = 1 + \frac{R_2}{R_1}$$



第十二章 回授與穩定度

<u>增益的敏感度</u>

$$\frac{dA_f}{dA}=\frac{1}{(1+\beta A)}-\frac{A}{(1+\beta A)^2}\cdot\beta=\frac{1}{(1+\beta A)^2}$$

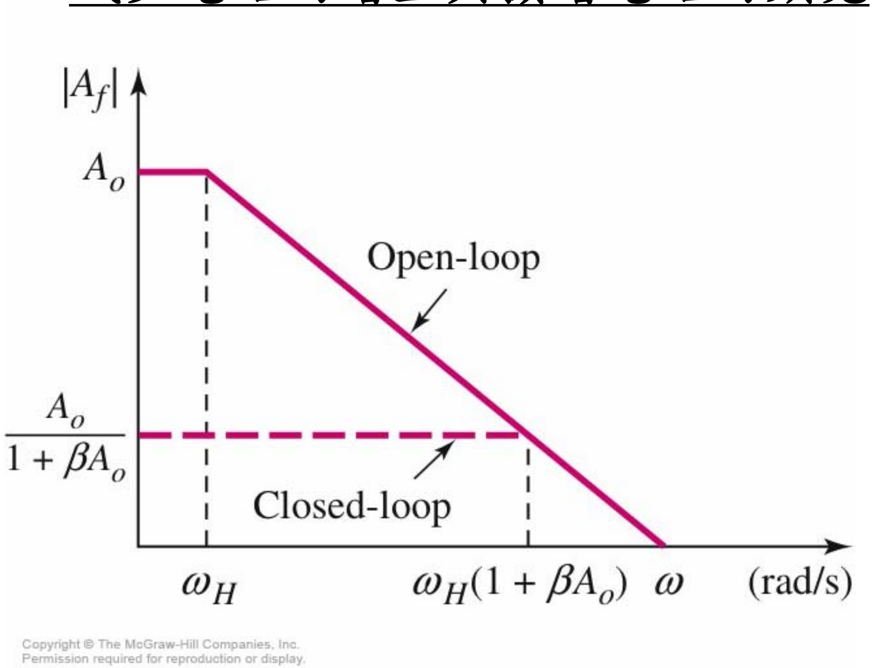
$$dA_f=\frac{dA}{(1+\beta A)^2}$$

$$\frac{dA_f}{A_f}=\frac{\dfrac{dA}{(1+\beta A)^2}}{\dfrac{A}{1+\beta A}}=\frac{1}{(1+\beta A)}\cdot\frac{dA}{A}=\left(\frac{A_f}{A}\right)\frac{dA}{A}$$

上式顯示出閉迴路增益 A_f之改變量相較於開迴路增益之改變量約小**(1+Aβ)**倍
→負回授減少增益的敏感度

第十二章 回授與穩定度

減少電路的增益與擴增電路的頻寬



$$A(s) = \frac{A_0}{1 + \frac{s}{\omega_H}}$$

A_0 為低頻或中頻增益

ω_H 為上限**3**分貝轉角頻率

閉迴路增益為

$$A_f(s) = \frac{A}{1+\beta A} = \frac{A_0}{(1+\beta A_0)} \cdot \frac{1}{1 + \frac{s}{\omega_H(1+\beta A_0)}}$$

低頻閉迴路增益 $\frac{A_0}{(1+\beta A_0)}$

閉迴路頻寬乘積為 $\omega_H(1+\beta A_0)$

低頻閉迴路增益與閉迴路頻寬的乘積為

$$\frac{A_0}{(1+A\beta)}\left[\omega_H(1+\beta A_0)\right] = A_0\omega_H$$

第十二章 回授與穩定度

降低雜訊的敏感度

負回授可降低放大器的雜訊準位(更精確來說負回授可增加信號對雜訊比值)

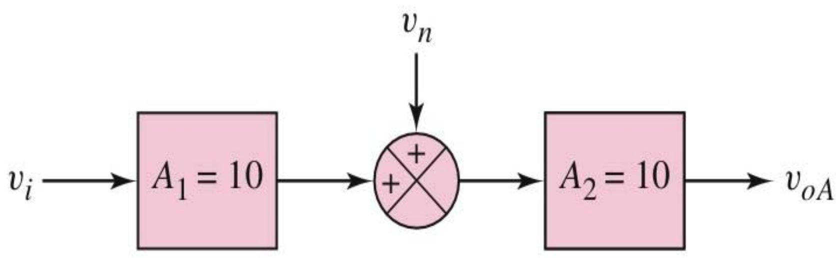
輸入之信號對雜訊比值為

$$(SNR)_i = \frac{S_i}{N_i} = \frac{v_i}{v_n}$$

輸出之信號對雜訊比值為

$$(SNR)_o = \frac{S_o}{N_o} = \frac{A_{Ti}S_i}{A_{Tn}N_i}$$

第十二章 回授與穩定度

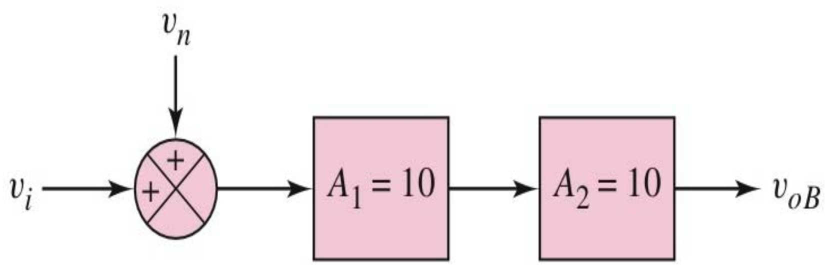


(a)

由圖 (a)

$$v_{oa} = A_1 A_2 v_i + A_2 v_n = 100 v_i + 10 v_n$$

$$\frac{S_o}{N_o} = \frac{100 v_i}{10 v_n} = 10 \frac{S_i}{N_i}$$



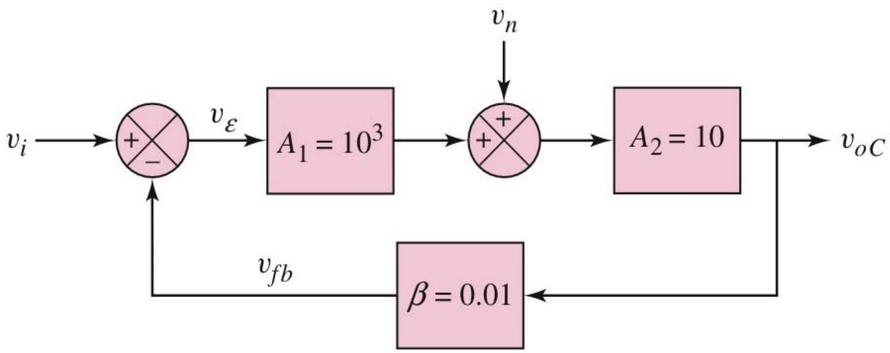
(b)

由圖 (b)

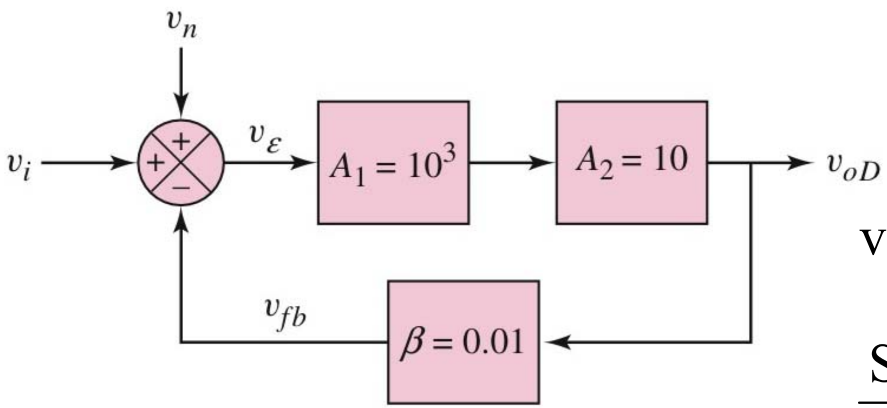
$$v_{ob} = A_1 A_2 v_i + A_1 A_2 v_n = 100 v_i + 100 v_n$$

$$\frac{S_o}{N_o} = \frac{100 v_i}{100 v_n} = \frac{S_i}{N_i}$$

第十二章 回授與穩定度



(c)



(d)

由圖 **(c)**

$$v_{oc} = A_1 A_2 v_\varepsilon + A_2 v_n$$

$$v_{fb} = \beta v_{oc} \qquad v_\varepsilon = v_i - v_{fb} = v_i - \beta v_{oc}$$

$$v_{oc} = A_1 A_2 \left(v_i - \beta v_{oc}\right) + A_2 v_n$$

$$= \frac{A_1 A_2}{\left(1 + \beta A_1 A_2\right)} \cdot v_i + \frac{A_2}{\left(1 + \beta A_1 A_2\right)} \cdot v_n$$

$$\cong 100 v_i + 0.1 v_n$$

$$\frac{S_0}{N_0} = \frac{100 v_i}{0.1 v_n} = 1000 \frac{S_i}{N_i}$$

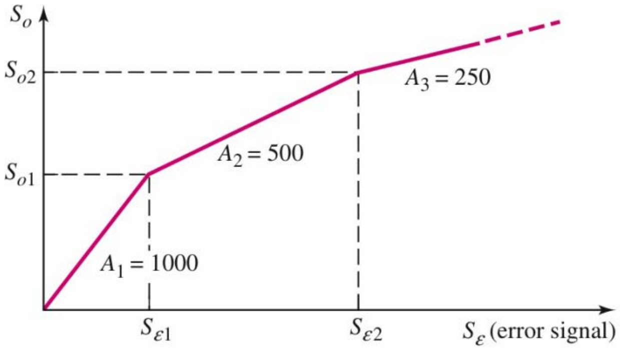
由圖 **(d)**

$$v_{od} = \frac{A_1 A_2}{\left(1 + \beta A_1 A_2\right)} \cdot \left(v_i + v_n\right) \cong 100 v_i + 100 v_n$$

$$\frac{S_0}{N_0} = \frac{100 v_i}{100 v_n} = \frac{S_i}{N_i}$$

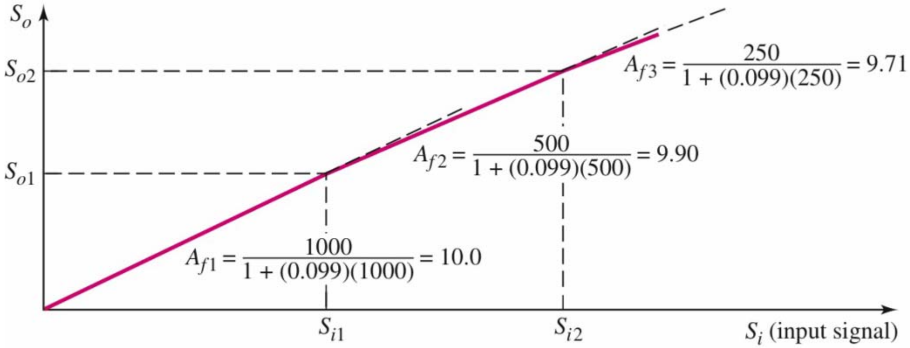
第十二章 回授與穩定度

減少非線性失真



(a)

圖 **(a)** 為基本放大器**(**開迴路**)**轉換特性。式子中顯現增益隨輸入信號改變而改變。



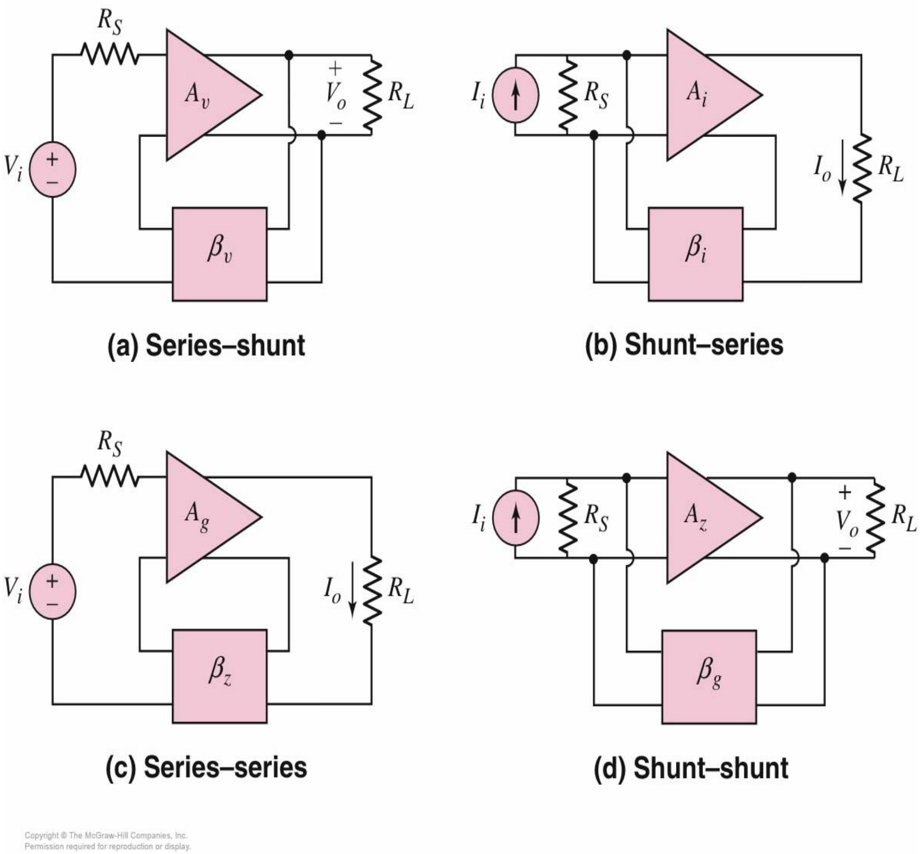
(b)

圖 **(b)**閉迴路轉換特性

開迴路增益變動 **2**倍時，其閉迴路增益只改變**1%**及**2%** 。

第十二章 回授與穩定度

12.3 四個理想回授電路之組態

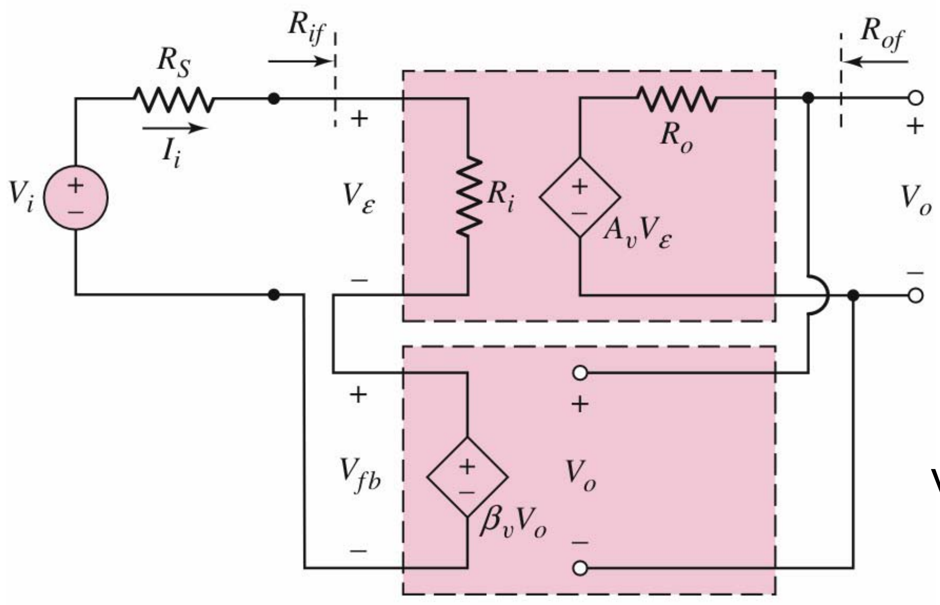


依照放大參數(電壓或電流)與輸出參數(電壓或電流)的不同，回授技術可分為四類：

(a) 串-並 => 電壓放大器
(b) 並-串 => 電流放大器
(c) 串-串 => 轉導放大器
(d) 並-並 => 轉阻放大器

第十二章 回授與穩定度

● 串-並組態(電壓放大器)



$$V_o = A_v V_\varepsilon$$

$$V_{fb} = \beta V_o = \beta_v V_o$$

$$V_\varepsilon = V_i - V_{fb}$$

$$A_{vf} = \frac{V_o}{V_i} = \frac{A_v}{(1+\beta_v A_v)}$$ 閉迴路電壓增益

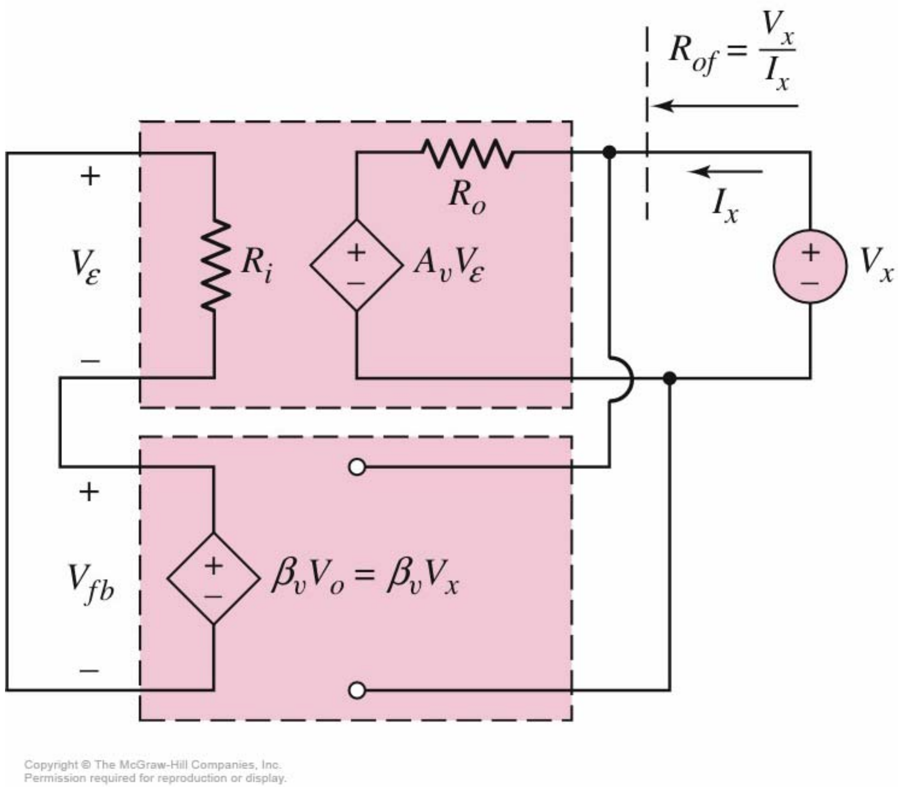
$$V_i = V_\varepsilon + V_{fb} = V_\varepsilon + \beta_v V_o$$
$$= V_\varepsilon + \beta_v (A_v V_\varepsilon)$$

$$V_\varepsilon = \frac{V_i}{(1+\beta_v A_v)}$$

$$I_i = \frac{V_\varepsilon}{R_i} = \frac{V_i}{R_i(1+\beta_v A_v)}$$

$$R_{if} = \frac{V_i}{I_i} = R_i(1+\beta_v A_v)$$ 輸入電阻↑

第十二章 回授與穩定度



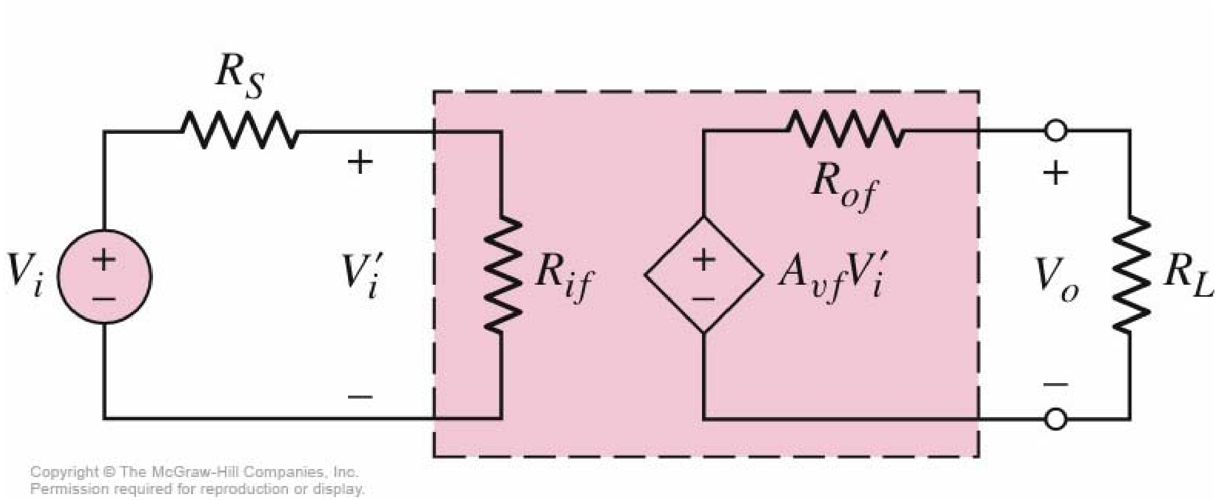
$$V_\varepsilon + V_{fb} = V_\varepsilon + \beta_v V_x = 0$$

$$V_\varepsilon = -V_{fb} = -\beta_v V_x$$

$$I_x = \frac{V_x - A_v V_\varepsilon}{R_o} = \frac{V_x - A_v\left(-\beta_v V_x\right)}{R_o} = \frac{V_x\left(1+\beta_v A_v\right)}{R_o}$$

$$R_{of} = \frac{V_x}{I_x} = \frac{R_o}{\left(1+\beta_v A_v\right)}$$ 輸出電阻↓

第十二章 回授與穩定度

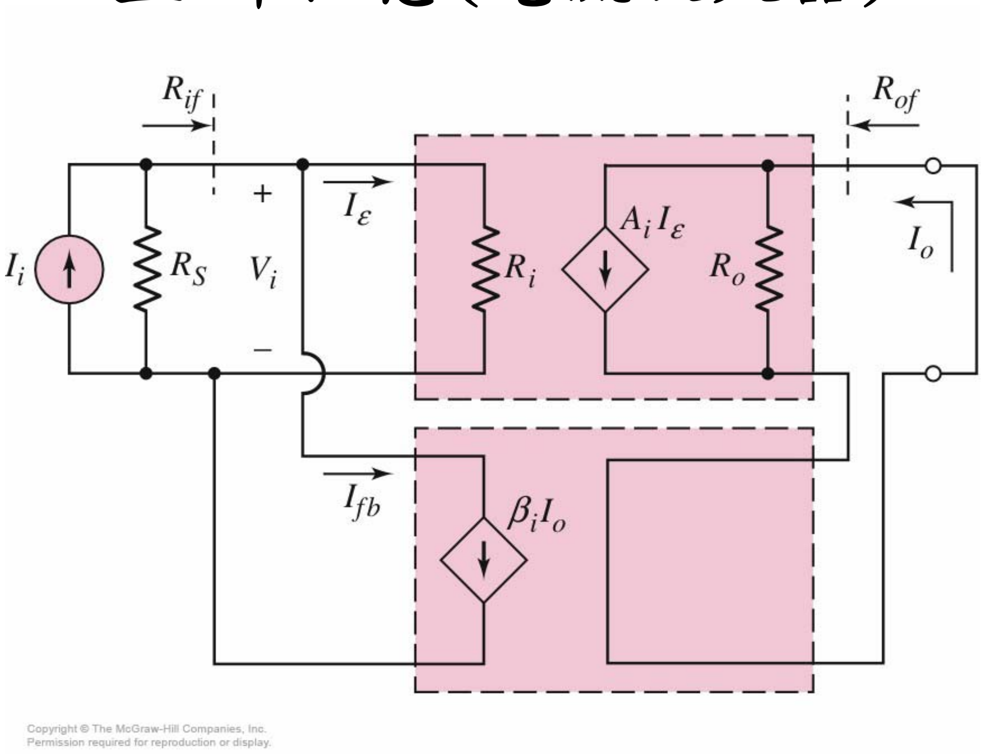


串-並回授電路或電壓放大器之等效電路

$$A_{vf} = \frac{A_v}{(1+\beta_v A_v)}; \qquad R_{of} = \frac{R_0}{(1+\beta_v A_v)}; \qquad R_{if} = R_i(1+\beta_v A_v)$$

第十二章 回授與穩定度

● 並-串組態(電流放大器)



$$I_O = A_i I_\varepsilon$$

$$I_{fb} = \beta I_o = \beta_i I_o$$

$$I_i = I_\varepsilon + I_{fb}$$

$$A_{if} = \frac{I_o}{I_i} = \frac{A_i}{(1+\beta_i A_i)}$$ 閉迴路電流增益

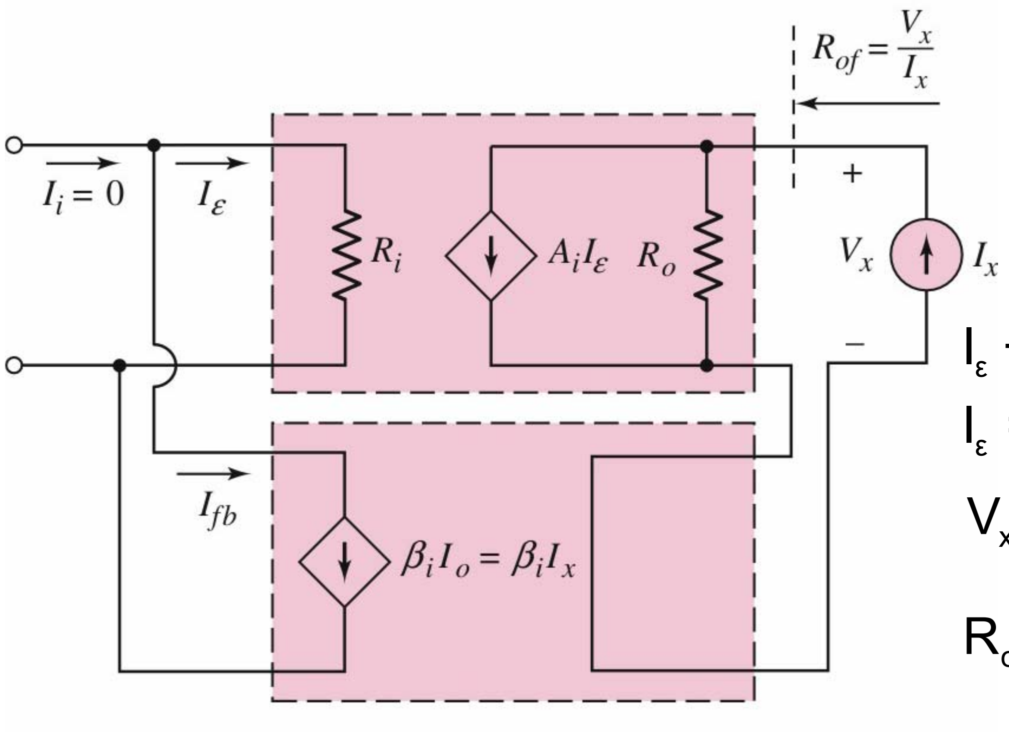
$$I_i = I_\varepsilon + I_{fb} = I_\varepsilon + \beta_i I_o = I_\varepsilon + \beta_i (A_i I_\varepsilon)$$

$$I_\varepsilon = \frac{I_i}{(1+\beta_i A_i)}$$

$$V_i = I_\varepsilon R_i = \frac{I_i R_i}{(1+\beta_i A_i)}$$

$$R_{if} = \frac{V_i}{I_i} = \frac{R_i}{(1+\beta_i A_i)}$$ 輸入電阻↓

第十二章 回授與穩定度



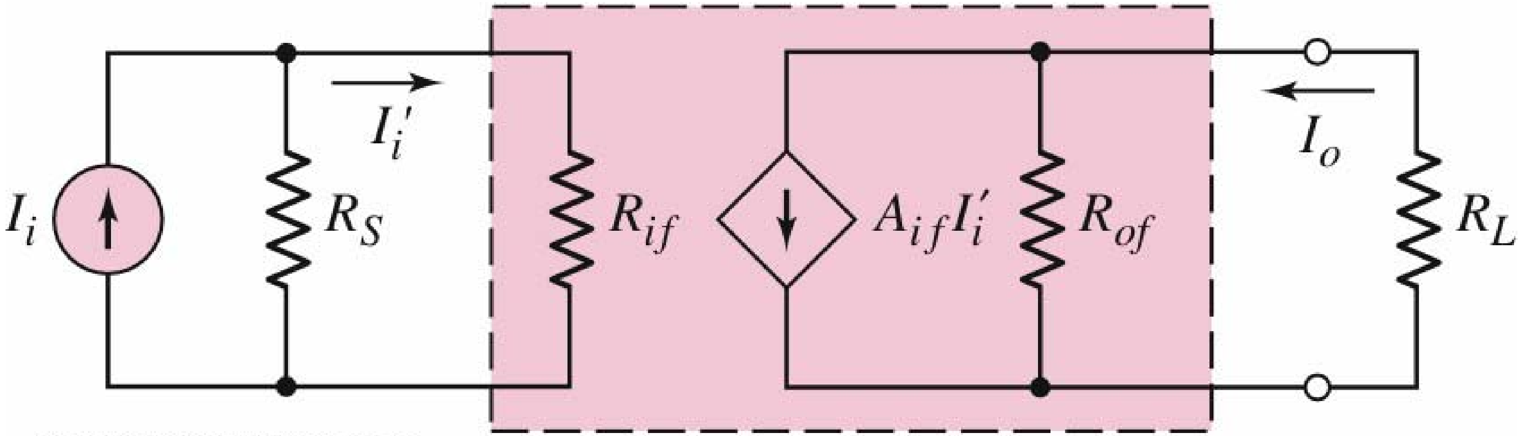
$$I_\varepsilon + I_{fb} = I_\varepsilon + \beta_i I_x = 0$$

$$I_\varepsilon = -I_{fb} = -\beta_i I_x$$

$$V_x = \left(I_x - A_i I_\varepsilon\right) R_o = [I_x - A_i\left(-\beta_i I_x\right)] R_o$$

$$R_{of} = \frac{V_x}{I_x} = \left(1 + \beta_i A_i\right) R_o$$ 輸出電阻↑

第十二章 回授與穩定度

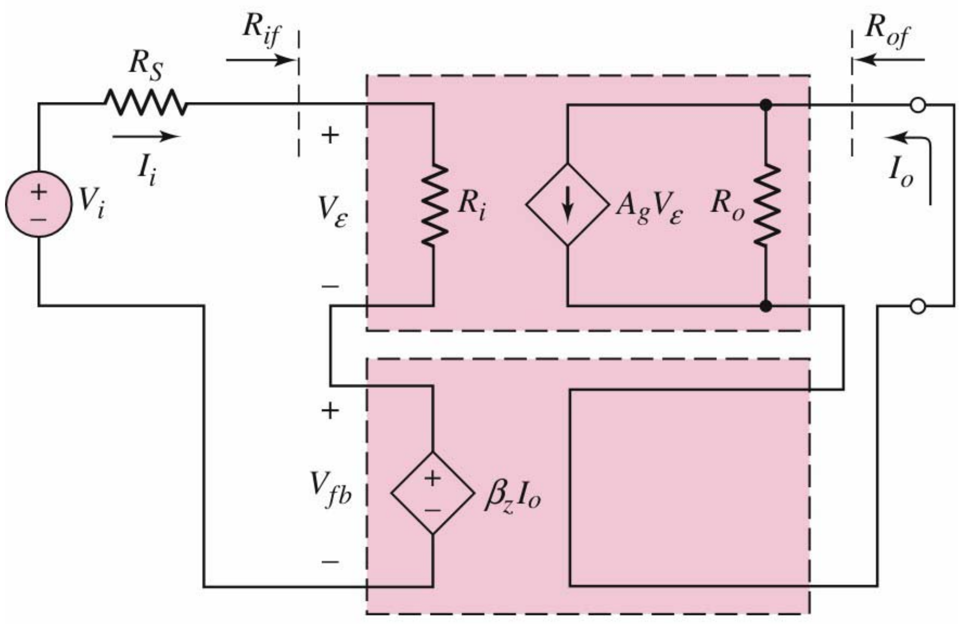


並-串回授電路或電流放大器之等效電路

$$A_{if} = \frac{A_i}{(1+\beta_i A_i)};\qquad R_{if} = \frac{R_i}{(1+\beta_i A_i)};\qquad R_{of} = R_o(1+\beta_i A_i)$$

第十二章 回授與穩定度

● 串-串組態(轉導放大器)



$$I_o = A_g V_\varepsilon$$

$$V_{fb} = \beta_z I_o$$

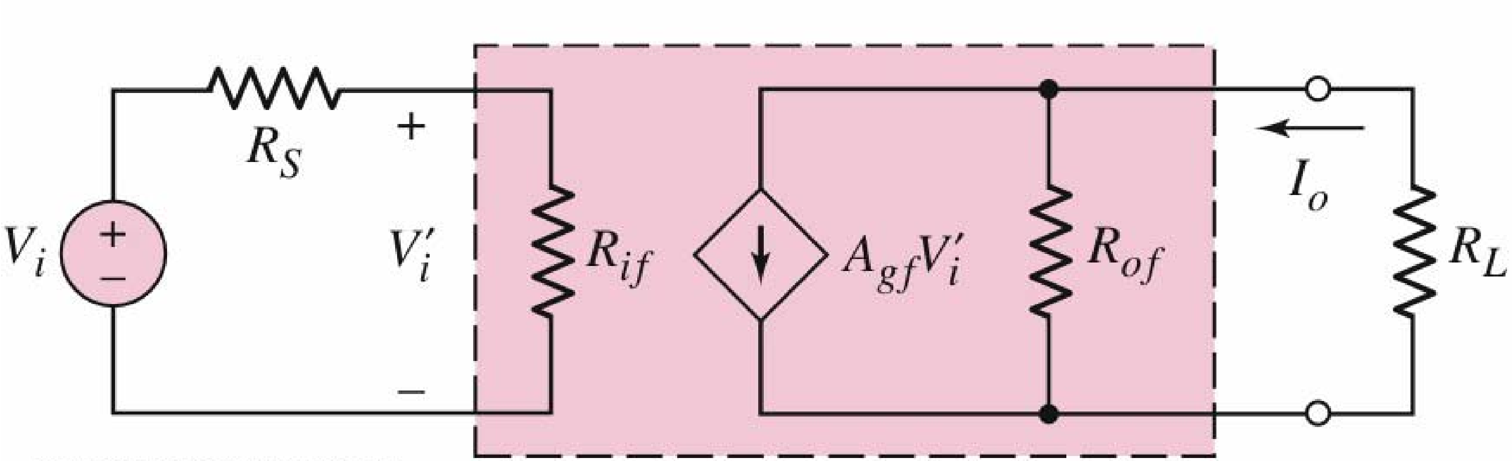
$$V_i = V_\varepsilon + V_{fb}$$

$$A_{gf} = \frac{I_o}{V_i} = \frac{A_g}{(1+\beta_z A_g)}$$

$$R_{if} = \frac{V_i}{I_i} = R_i(1+\beta_z A_g)$$ 輸入電阻↑

$$R_{of} = \frac{V_o}{I_o} = R_o(1+\beta_z A_g)$$ 輸出電阻↑

第十二章 回授與穩定度

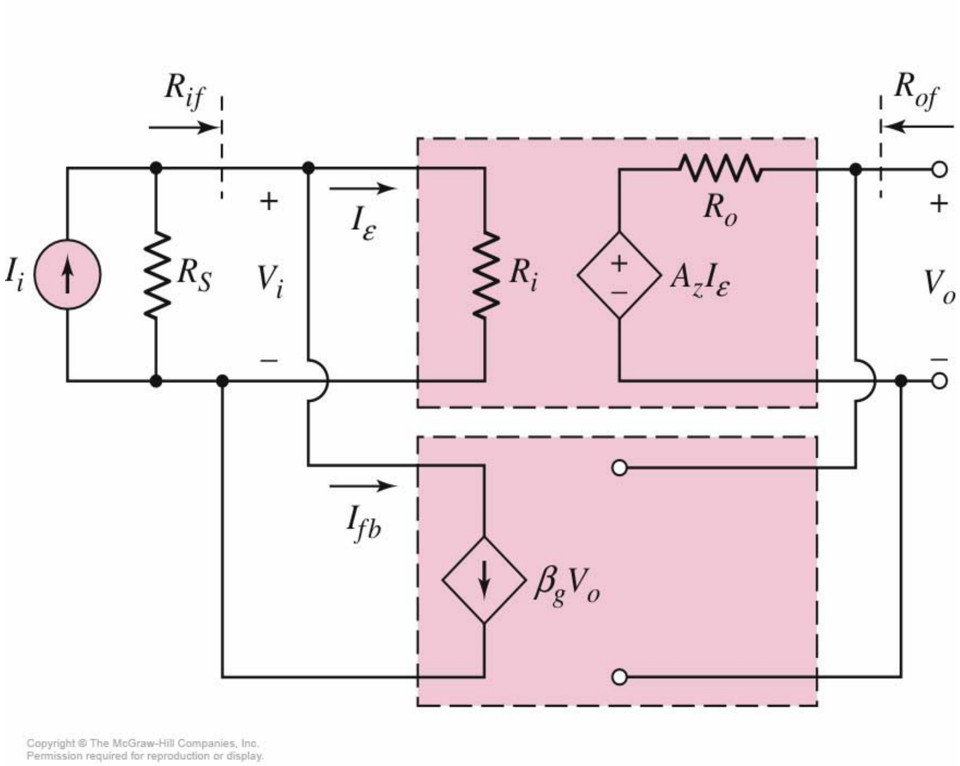


串-串回授電路或轉導放大器之等效電路

$$A_{gf} = \frac{A_g}{(1+\beta_z A_g)}; \qquad R_{if} = R_i(1+\beta_z A_g); \qquad R_{of} = R_o(1+\beta_z A_g)$$

第十二章 回授與穩定度

● 並-並組態(轉阻放大器)



$$V_o = A_z I_\varepsilon$$

$$I_{fb} = \beta_g V_o$$

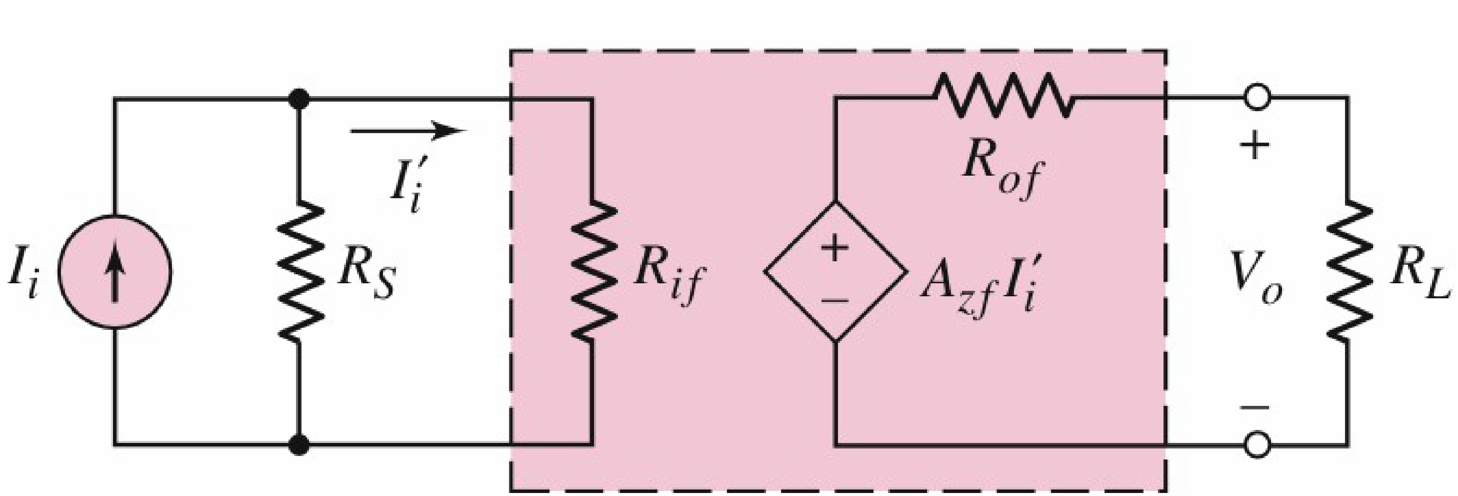
$$I_i = I_\varepsilon + I_{fb}$$

$$A_{zf} = \frac{V_o}{I_i} = \frac{A_z}{(1+\beta_g A_z)}$$

$$R_{if} = \frac{V_i}{I_i} = \frac{R_i}{(1+\beta_g A_z)}$$ 輸入電阻↓

$$R_{of} = \frac{V_o}{I_o} = \frac{R_o}{(1+\beta_g A_z)}$$ 輸出電阻↓

第十二章 回授與穩定度



並-並回授電路或轉導放大器之等效電路

$$A_{zf} = \frac{A_z}{(1+\beta_g A_z)}; \qquad R_{if} = \frac{R_i}{(1+\beta_g A_z)}; \qquad R_{of} = \frac{R_o}{(1+\beta_g A_z)}$$

12.21 Consider the noninverting op-amp circuit in Figure P12.20. The input resistance of the op-amp is $R_i=\infty$ and the output resistance is $R_o=0$, but the op-amp has a finite gain A.

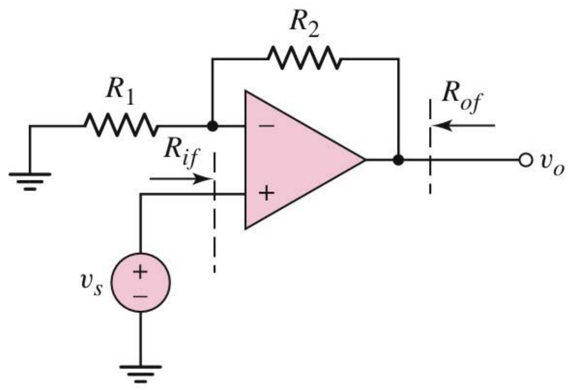
(a) Write the closed-loop transfer function in the form

$$A_{vf}=\frac{v_o}{v_s}=\frac{A}{(1+\beta A)}$$

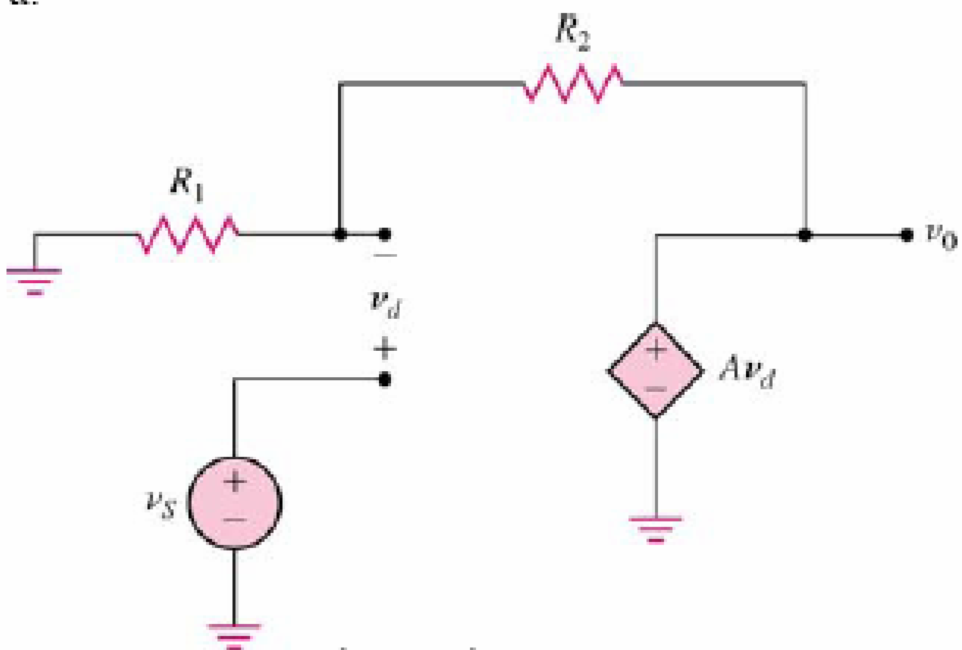
(b) What is the expression for β?

(c) If $A=10^5$ and $A_{vf}=20$, what is the required β and R_2/R_1?

(d) If A decreases by 10%, what is the % change in A_{vf}?



a.



$$\frac{v_S - v_d}{R_1} = \frac{v_0 - (v_S - v_d)}{R_2} \text{ and } v_d = \frac{v_0}{A}$$

$$v_S\left(\frac{1}{R_1} + \frac{1}{R_2}\right) = \frac{v_0}{R_2}\left[1 + \frac{1}{A}\left(1 + \frac{R_2}{R_1}\right)\right]$$

$$A_{vf} = \frac{v_0}{v_S} = \frac{A}{1 + \left[A / \left(1 + \frac{R_2}{R_1}\right)\right]}$$

b.

$$\beta = \frac{1}{1 + \frac{R_2}{R_1}}$$

c.

$$20 = \frac{10^5}{1 + (10^5)\beta}$$

So $\beta = \dfrac{\frac{10^5}{20} - 1}{10^5} \Rightarrow \underline{\beta = 0.04999}$

Then $\dfrac{R_2}{R_1} = \dfrac{1}{\beta} - 1 = \dfrac{1}{0.04999} - 1$

$$\Rightarrow \underline{\frac{R_2}{R_1} = 19.004}$$

d.

$$A \to 9 \times 10^4$$

$$A_f = \frac{9 \times 10^4}{1 + (9 \times 10^4)(0.04999)} = 19.99956$$

$$\frac{\Delta A_f}{A_f} = \frac{-4.444 \times 10^{-4}}{20} = -2.222 \times 10^{-3}\%$$

$$\Rightarrow \underline{\frac{\Delta A_f}{A_f} = -0.005\%}$$

12.24 Consider the op-amp circuit in Figure P12.24. The op-amp has a finite gain, so that $i_o = A i_\varepsilon$, and a zero output impedance.

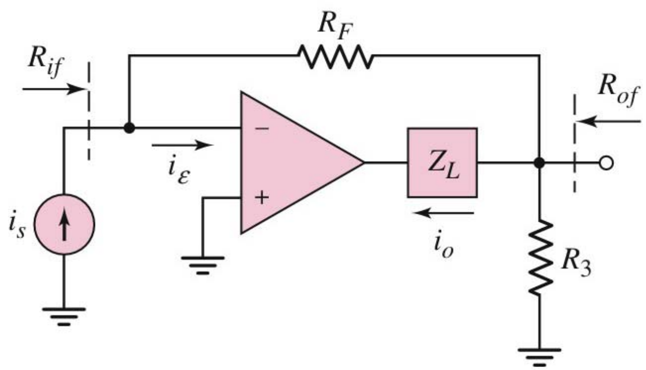
(a) Write the closed-loop transfer function in the form

$$A_{if} = \frac{i_o}{i_s} = \frac{A_i}{(1+\beta_i A_i)}$$

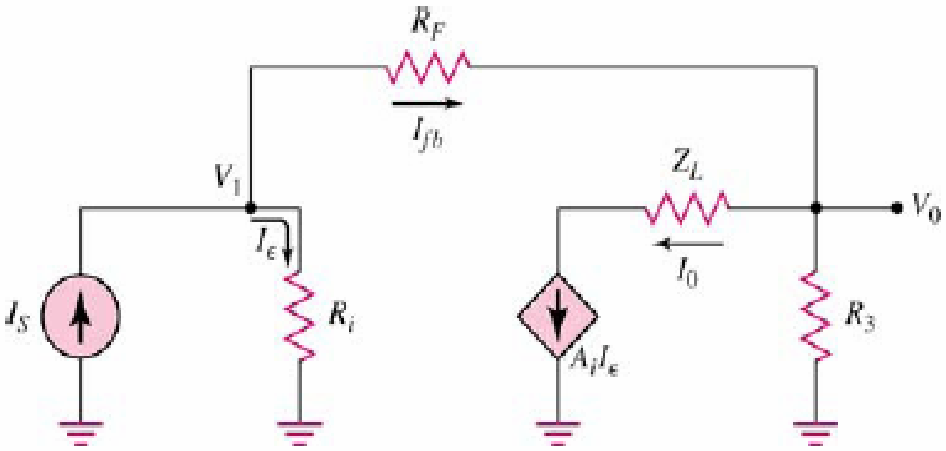
(b) What is the expression for β_i?

(c) If $A_i = 10^5$ and $A_{if} = 25$, what is the required β_i and R_F/R_3?

(d) If A_i decreases by 15%, what is the % change in A_{if}?



a.



Assume that V_1 is at virtual ground. $V_0 = -I_{fb}R_F$

$$I_{fb} = I_0 + \frac{V_0}{R_3} = I_0 - \frac{I_{fb}R_F}{R_3}$$

$I_{fb} = I_S - I_\epsilon$ and $I_0 = A_i I_\epsilon = \frac{I_0}{A_i}$

so $I_{fb} = I_S - \frac{I_0}{A_i}$

$$I_0 = I_{fb}\left(1+\frac{R_F}{R_3}\right) = \left(I_S - \frac{I_0}{A_i}\right)\left(1+\frac{R_F}{R_3}\right)$$

$$A_{if} = \frac{I_0}{I_S} = \frac{\left(1+\frac{R_F}{R_3}\right)}{\left[1+\frac{1}{A_i}\left(1+\frac{R_F}{R_3}\right)\right]} = \frac{A_i}{1+\frac{A_i}{\left(1+\frac{R_F}{R_3}\right)}} = A_{if}$$

b. $$\beta_i = \frac{1}{\left(1+\frac{R_F}{R_3}\right)}$$

c. $$25 = \frac{10^5}{1+(10^5)\beta_i}$$

so $\beta_i = \frac{\frac{10^5}{25}-1}{10^5} \Rightarrow \underline{\beta_i = 0.03999}$

so $\frac{R_F}{R_3} = \frac{1}{\beta_i} - 1 = \frac{1}{0.03999} - 1 \Rightarrow \underline{\frac{R_F}{R_3} = 24.0}$

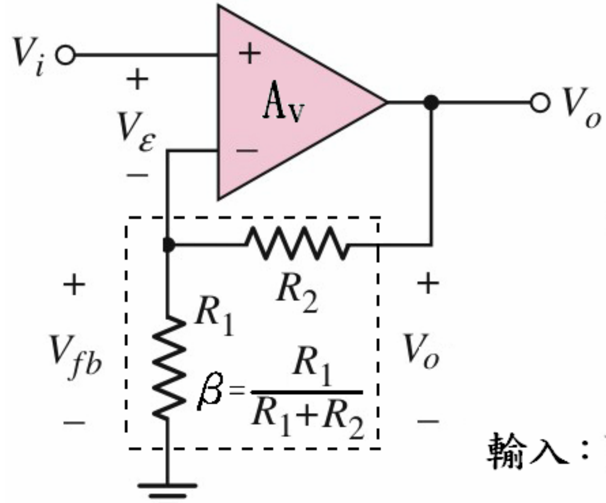
d. $A_i = 10^5 - (0.15)(10^5) = 8.5\times10^4$

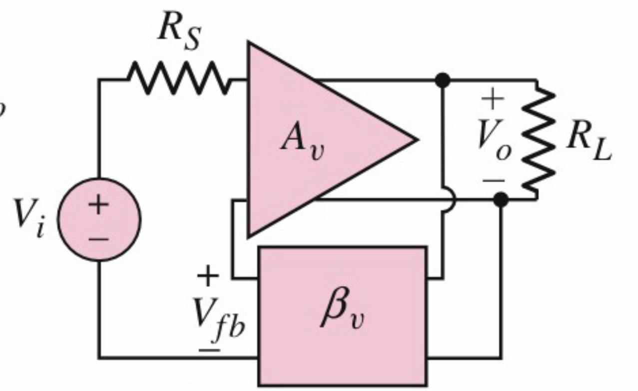
so $A_{if} = \frac{8.5\times10^4}{1+(8.5\times10^4)(0.03999)} = 24.9989$

so $\frac{\Delta A_{if}}{A_{if}} = -\frac{1.10\times10^{-3}}{25} = -4.41\times10^{-5} \Rightarrow \underline{-4.41\times10^{-3}\%}$

第十二章 回授與穩定度

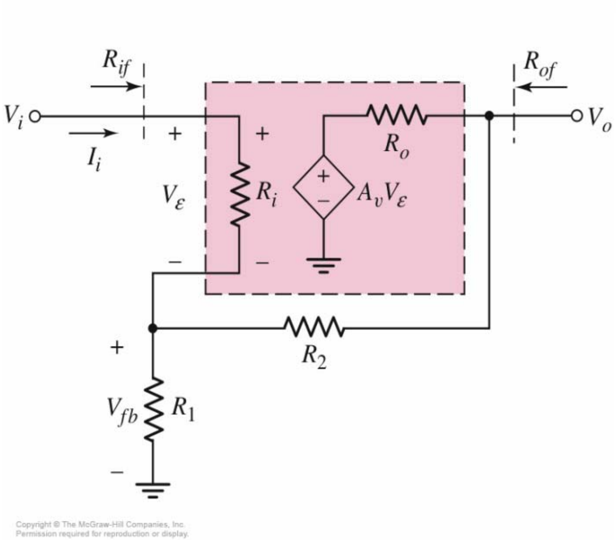
12.4 串-並回授組態





輸入：$V_\varepsilon = V_i - V_{fb}$ (串)；輸出：$V_{fb} = \beta V_o$ (並)

$$V_o = A_v V_\varepsilon = A_v(V_i - V_{fb}) = A_v(V_i - \beta V_o) \rightarrow A_{vf} = \frac{V_o}{V_i} = \frac{A_v}{1+A_v\beta} = \frac{A_v}{1+A_v\frac{R_1}{R_1+R_2}}$$

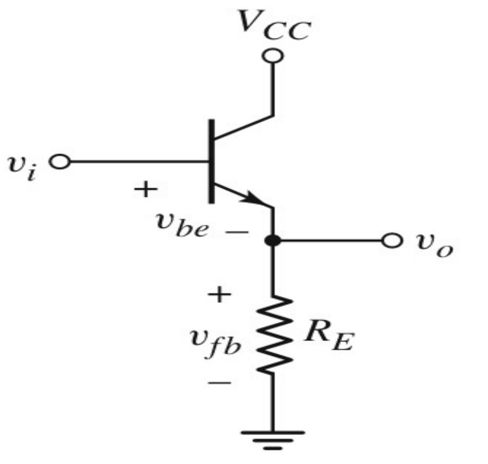


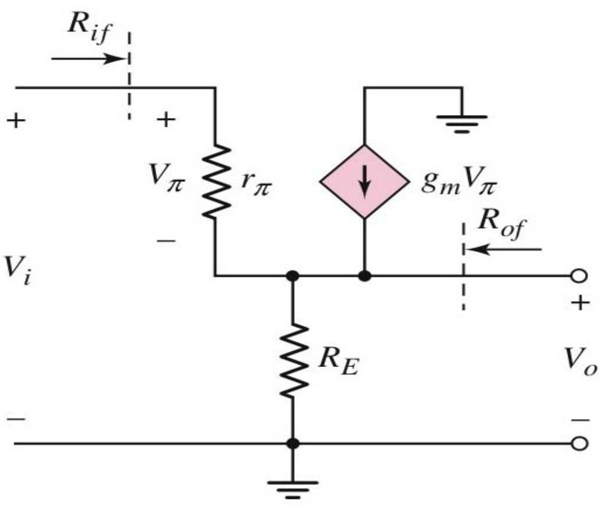
$$\mathbf{V_i} = \mathbf{V_\varepsilon} + \left(\frac{\mathbf{R_1}}{\mathbf{R_1}+\mathbf{R_2}}\right)\mathbf{V_o} = \mathbf{V_\varepsilon} + \frac{\mathbf{A_v V_\varepsilon}}{\left(1+\frac{\mathbf{R_2}}{\mathbf{R_1}}\right)} = \mathbf{V_\varepsilon}\left[1+\frac{\mathbf{A_v}}{\left(1+\frac{\mathbf{R_2}}{\mathbf{R_1}}\right)}\right]$$

$$\mathbf{R_{if}} = \frac{\mathbf{V_i}}{\mathbf{I_i}} = \frac{\mathbf{V_i}}{(\mathbf{V_\varepsilon}/\mathbf{R_i})} = \mathbf{R_i}\left[1+\frac{\mathbf{A_v}}{\left(1+\left(\frac{\mathbf{R_2}}{\mathbf{R_1}}\right)\right)}\right]$$

$$= \mathbf{R_i}(1+\beta_v\mathbf{A_v})$$

第十二章 回授與穩定度





(c)

$$A_{vf}=\frac{V_o}{V_i}=\frac{\left(\frac{1}{r_\pi}+g_m\right)R_E}{1+\left(\frac{1}{r_\pi}+g_m\right)R_E}=\frac{\frac{R_E}{r_e}}{1+\frac{R_E}{r_e}}$$

$$r_e=\frac{r_\pi}{(1+g_m r_\pi)}$$

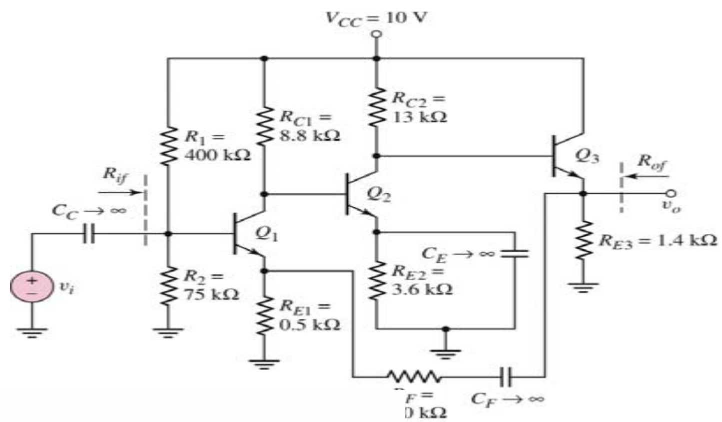
$$A_v=\left(\frac{1}{r_\pi}+g_m\right)R_E=\frac{R_E}{r_e}\ ; \quad \beta=1,(V_o=V_{\mathrm{fb}})$$

$$R_{if}=r_\pi+(1+h_{FE})R_E=r_\pi\left[1+\left(\frac{1}{r_\pi}+g_m\right)R_E\right]$$

$$R_{of}=R_E\parallel\frac{r_\pi}{(1+h_{FE})}=R_E\parallel r_e$$

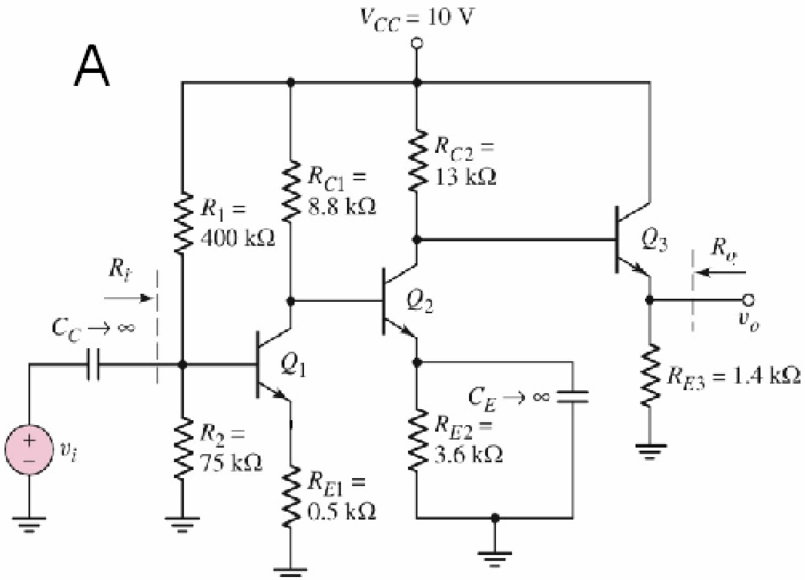
$$R_{of}=\frac{R_E}{1+\left(\frac{1}{r_\pi}+g_m\right)R_E}$$

Draw the circuits of basic blocks A and β, and find the value of β.

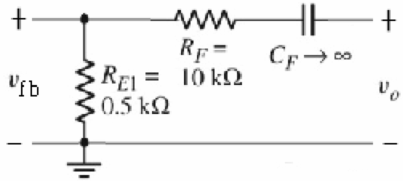


Ans:

A

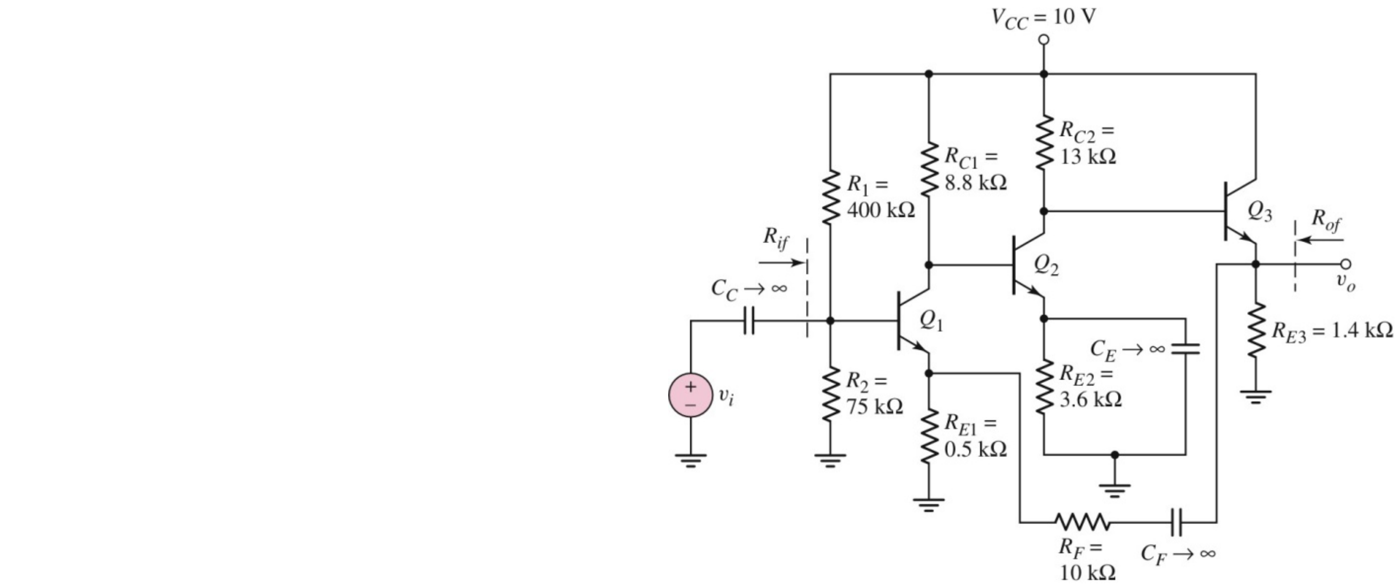


β



$$\beta = \frac{R_{E1}}{R_F + R_{E1}} = \frac{0.5K}{10K + 0.5K} = 1/21$$

12.36 Consider the series-shunt feedback circuit in Figure P12.36, with transistor parameters: h_{FE}=120, $V_{BE(on)}$=0.7V, and $V_A=\infty$. (a) Determine the small-signal parameters for Q_1, Q_2, and Q_3. Using nodal analysis, determine: (b) the small-signal voltage gain $A_{vf}=v_o/v_i$. (c) the input resistance R_{if}, and (d) the output resistance R_{of}.



a. $R_{TH} = R_1 \parallel R_2 = 400 \parallel 75 = 63.2 \text{ k}\Omega$

$$V_{TH} = \left(\frac{R_2}{R_1 + R_2}\right)V_{CC} = \left(\frac{75}{75+400}\right)(10) = 1.579 \text{ V}$$

$$I_{BQ1} = \frac{1.579 - 0.7}{63.2 + (121)(0.5)} = 0.007106 \text{ mA}$$

$$I_{CQ1} = 0.853 \text{ mA}$$

$$V_{C1} = 10 - (0.853)(8.8) = 2.49 \text{ V}$$

$$I_{C2} \approx \frac{2.49 - 0.7}{3.6} = 0.497 \text{ mA}$$

$$V_{C2} = 10 - (0.497)(13) = 3.54 \text{ V}$$

$$I_{C3} \approx \frac{3.54 - 0.7}{1.4} = 2.03 \text{ mA}$$

Then

$$r_{\pi1} = \frac{(120)(0.026)}{0.853} = 3.66 \text{ k}\Omega$$

$$g_{m1} = \frac{0.853}{0.026} = 32.81 \text{ mA/V}$$

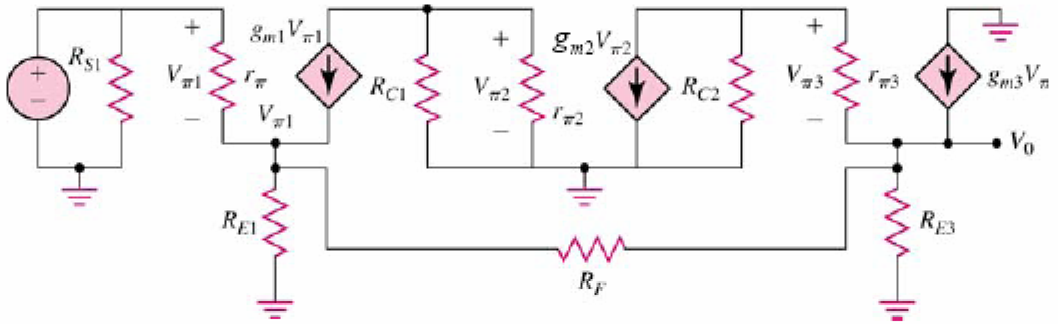
$$r_{\pi2} = \frac{(120)(0.026)}{0.497} = 6.28 \text{ k}\Omega$$

$$g_{m2} = \frac{0.497}{0.026} = 19.12 \text{ mA/V}$$

$$r_{\pi3} = \frac{(120)(0.026)}{2.03} = 1.54 \text{ k}\Omega$$

$$g_{m3} = \frac{2.03}{0.026} = 78.08 \text{ mA/V}$$

b.



$$V_i = V_{\pi1} + V_{e1} \Rightarrow V_{e1} = V_i - V_{\pi1} \qquad (1)$$

$$\frac{V_{\pi1}}{r_{\pi1}} + g_{m1}V_{\pi1} = V_{\pi1}(35.18) = \frac{V_{e1}}{R_{E1}} + \frac{V_{e1} - V_0}{R_F} = (V_i - V_{\pi1})\left(\frac{1}{0.5} + \frac{1}{10}\right) - \frac{V_0}{10} = V_i(2.10) - V_0(0.10) \qquad (2)$$

$$V_{\pi2} = -(g_{m1}V_{\pi1})(R_{C1} \parallel r_{\pi2}) = -(32.81)V_{\pi1}(88 \parallel 6.28) = -V_{\pi1}(120.2) \qquad (3)$$

$$g_{m2}V_{\pi2} + \frac{V_{\pi3} + V_0}{R_{C2}} + \frac{V_{\pi3}}{r_{\pi3}} = V_{\pi2}(19.12) + V_{\pi3}(0.7263) + V_0(0.07692) = 0 \qquad (4)$$

$$\frac{V_{\pi3}}{r_{\pi3}} + g_{m3}V_{\pi3} = V_{\pi3}(78.73) = \frac{V_0}{R_{E3}} + \frac{V_0 - V_{e1}}{R_F} = V_0(0.8143) - V_i(0.10) + V_{\pi1}(0.10) \qquad (5)$$

Now substituting $V_{\pi2} = -V_{\pi1}(120.2)$ in (4):

$(19.12)[-V_{\pi1}(120.2)] + V_{\pi3}(0.7263) + V_0(0.07692) = 0$

$-V_{\pi1}(2298.2) + V_{\pi3}(0.7263) + V_0(0.07692) = 0$ Then $V_{\pi3} = V_{\pi1}(3164.3) - V_0(0.1059)$

Substituting $V_{\pi3} = V_{\pi1}(3164.3) - V_0(0.1059)$ in (5):

$(78.73)[V_{\pi1}(3164.3) - V_0(0.1059)] = V_0(0.8143) - V_i(0.10) + V_{\pi1}(0.10)$

or $V_{\pi1}(2.49\times10^5) - V_0(9.152) = -V_i(0.10)$

Then $V_{\pi1} = V_0(3.674\times10^{-5}) - V_i(4.014\times10^{-7})$

in (2): $(35.18)[V_0(3.674\times10^{-5}) - V_i(4.014\times10^{-7})]$

Now substituting $V_{\pi1} = V_0(3.674\times10^{-5}) = V_i(2.10) - V_0(0.10)$

or $V_0(0.1013) = V_i(2.10)$ So $\dfrac{V_0}{V_i} = 20.7$

c. $R_{if} = \frac{V_i}{I_i}$ and $I_i = I_{RB1} + I_{b1}$

$I_{RB1} = \frac{V_i}{R_{B1}}$ $\qquad I_{b1} = \frac{V_{\pi 1}}{r_{\pi 1}}$

$$V_{\pi 1} = (20.7V_i)(3.674\times 10^{-5}) - V_i(4.014\times 10^{-7})$$
$$= V_i(7.60\times 10^{-4})$$

Then

$$R_{if} = \frac{V_i}{\frac{V_i}{63.2} + \frac{V_i(7.60\times 10^{-4})}{3.66}}$$
$$= \frac{1}{0.01582 + 2.077\times 10^{-4}} = \underline{62.4\text{ k}\Omega}$$

d. $V_i = 0$ Equation (1) is modified to $V_{\pi 1} + V_{e1} = 0$

Equation (5) is modified to:

$V_{\pi 3}(78.73) + I_X = V_0(0.8143) + V_{\pi 1}(0.10)$ (5)

Now

$V_{\pi 1}(35.18) = -V_0(0.10)$ (2)

$V_{\pi 2} = -V_{\pi 1}(120.2)$ (3)

$V_{\pi 2}(19.12) + V_{\pi 3}(0.7263) + V_0(0.07692) = 0$ (4)

Now

$V_{\pi 1} = -V_0(0.002843)$

so

$V_{\pi 2} = -(-V_0)(0.002843)(120.2)$

$V_{\pi 2} = V_0(0.3417)$

Then

$V_0(0.3417)(19.12) + V_{\pi 3} + (0.7263) + V_0(0.07692) = 0$

or $V_{\pi 3} = -V_0(9.101)$ (4)

So then

$-V_0(9.101)(78.73) + I_X$
$= V_0(0.8143) + (0.10)(-V_0)(0.002843)$

or

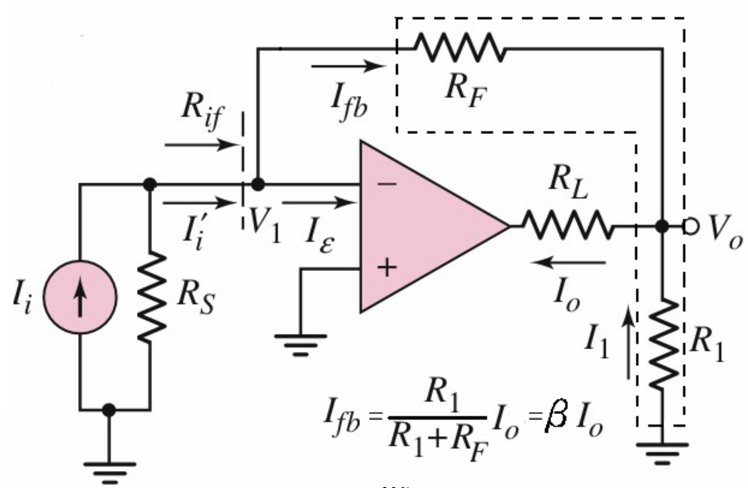
$I_X = V_0(717.3)$ (5)

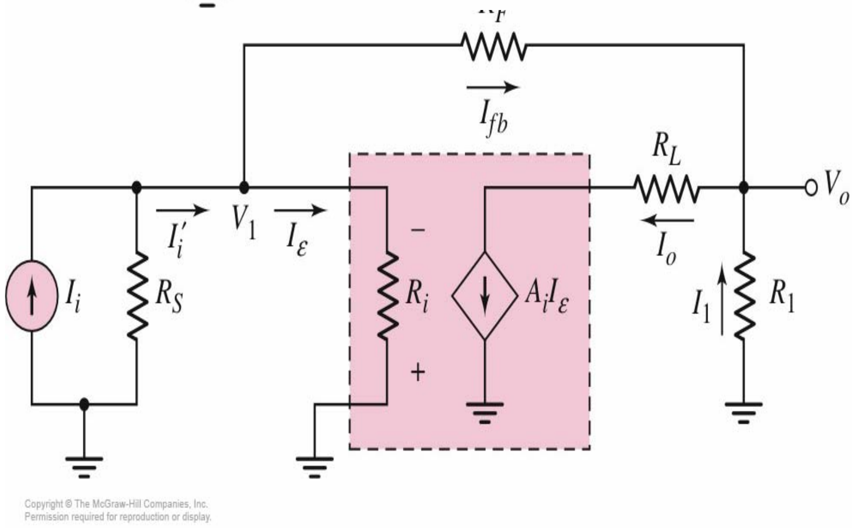
or

$$R_{0f} = \frac{V_0}{I_X} = 0.00139\text{ k}\Omega \Rightarrow \underline{R_{0f} = 1.39\ \Omega}$$

第十二章 回授與穩定度

12.5 並-串回授組態





$$I_i \cong I_i' = I_{fb}$$

$$V_o = -I_{fb}R_F = -I_i R_F$$

$$I_o = I_{fb} + I_1 = I_i + \left(-\frac{1}{R_1}\right)(-I_i R_F) = I_i\left(1+\frac{R_F}{R_1}\right)$$

$$\frac{I_o}{I_i} = 1 + \frac{R_F}{R_1}$$

$$A_{if} = \frac{I_o}{I_i} = \frac{1}{\beta_i}$$

$$\beta_i = \frac{1}{1+\frac{R_F}{R_1}}$$

就有限放大增益而言

$$I_o = A_i I_\varepsilon$$

$$I_\varepsilon = I_i' - I_{fb} \cong I_i - I_{fb}$$

$$I_o = A_i\left(I_i - I_{fb}\right)$$

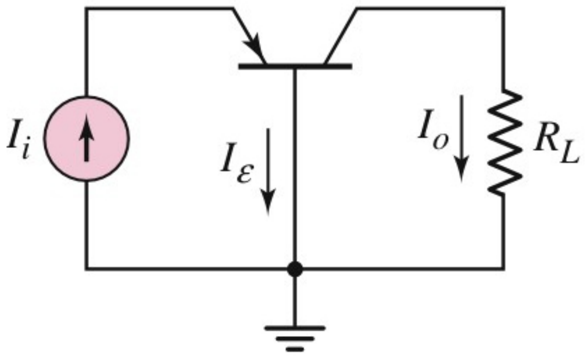
$$V_o = -I_{fb}R_F$$

$$I_1 = -\frac{V_o}{R_1} = -\left(\frac{1}{R_1}\right)(-I_{fb}R_F) = I_{fb}\left(\frac{R_F}{R_1}\right)$$

$$I_o = I_{fb} + I_1 = I_{fb} + I_{fb}\left(\frac{R_F}{R_1}\right)$$

$$A_{if} = \frac{I_o}{I_i} = \frac{A_i}{1+\frac{A_i}{\left(1+\frac{R_F}{R_1}\right)}}$$

第十二章 回授與穩定度



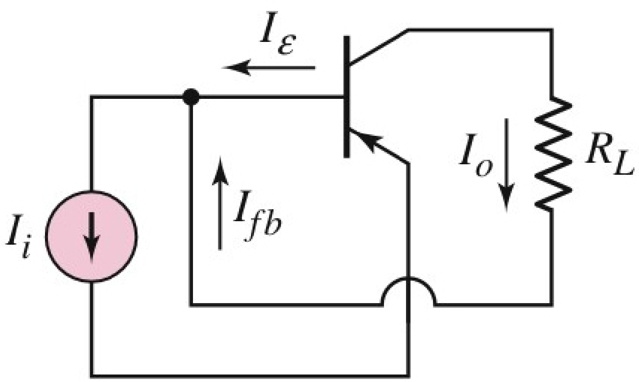
(a)

基本放大增益為

$$I_o / I_\varepsilon = A_i = h_{FE}$$

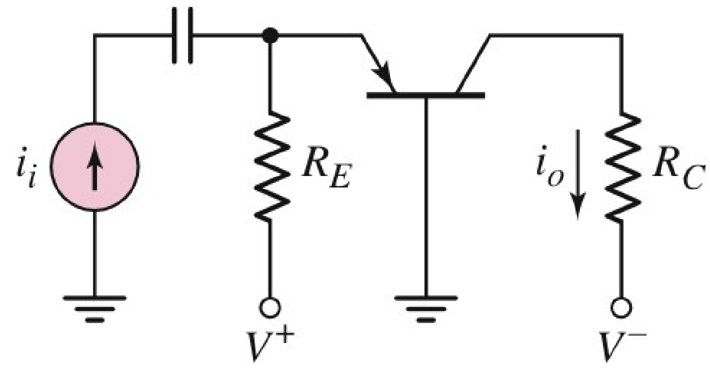
閉迴路電流轉換方程式或增益可表示為

$$A_{if} = \frac{I_o}{I_i} = \frac{h_{FE}}{1+h_{FE}} = \frac{A_i}{1+A_i}$$



(b)

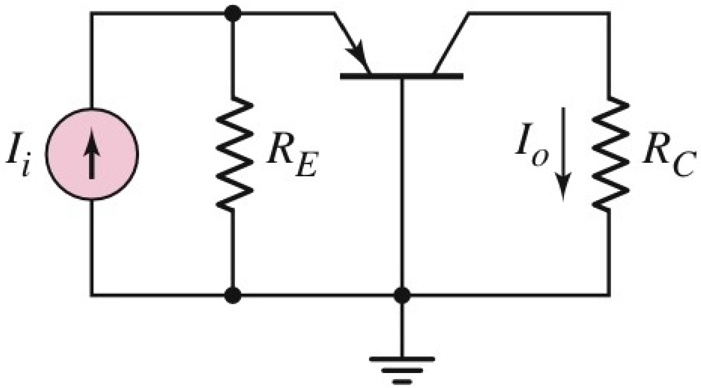
第十二章 回授與穩定度



(a)

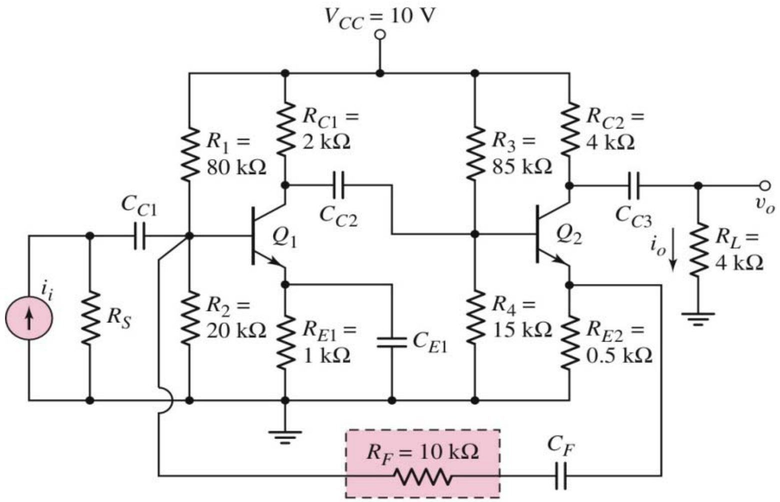
圖(a)中為更實際的共基極電流增益電路

$$A_{if} = \frac{I_o}{I_i} = \frac{h_{FE}}{\left(1 + \frac{r_\pi}{R_E}\right) + h_{FE}} = \frac{A_i}{\left(1 + \frac{r_\pi}{R_E}\right) + A_i}$$

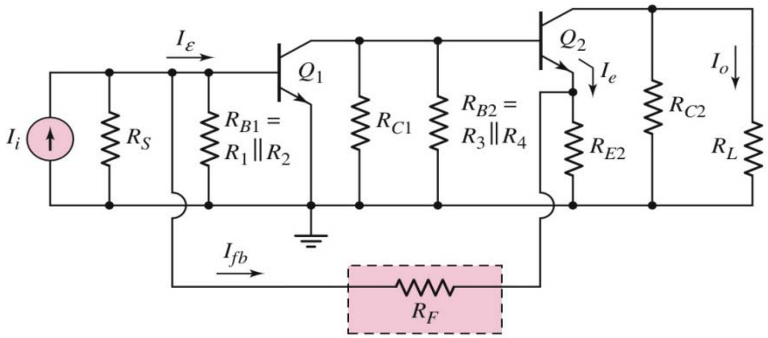


(b)

第十二章 回授與穩定度

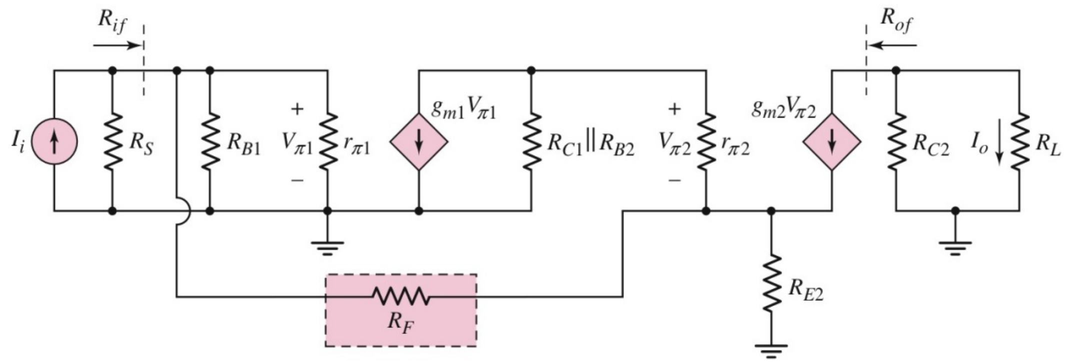


(a)

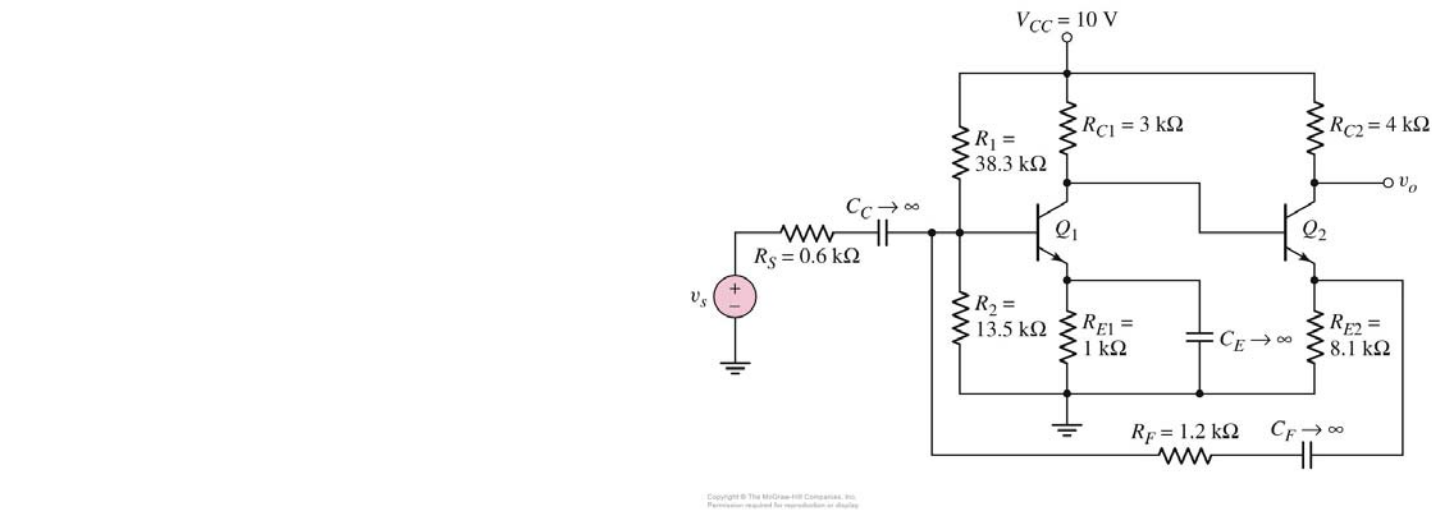


(b)

圖**(a)**為離散電晶體並**-**串回授電路的例子**;**
圖**(b)**為交流等效電路。
其中負載電流 I_o及回授電流 I_{fb} 正比於射極電流I_e 。
下圖為小信號等效電路。



12.46 The circuit in Figure P12.46 is an example of a shunt-series feedback circuit. A signal proportional to the output current is fed back to the shunt connection at the base of Q_1. However, the circuit may be used as a voltage amplifier. Assume transistor parameter of h_{FE}=120, $V_{BE(on)}$=0.7V, and $V_A=\infty$. (a) Determine the small-signal parameters for Q_1 and Q_2. (b) Using nodal analysis, determine the small-signal voltage gain $A_v=v_o/v_s$.



a. $$R_{TH} = 13.5 \| 38.3 = 9.98 \text{ k}\Omega \qquad V_{TH} = \left(\frac{13.5}{13.5+38.3}\right)(10) = 2.606 \text{ V}$$

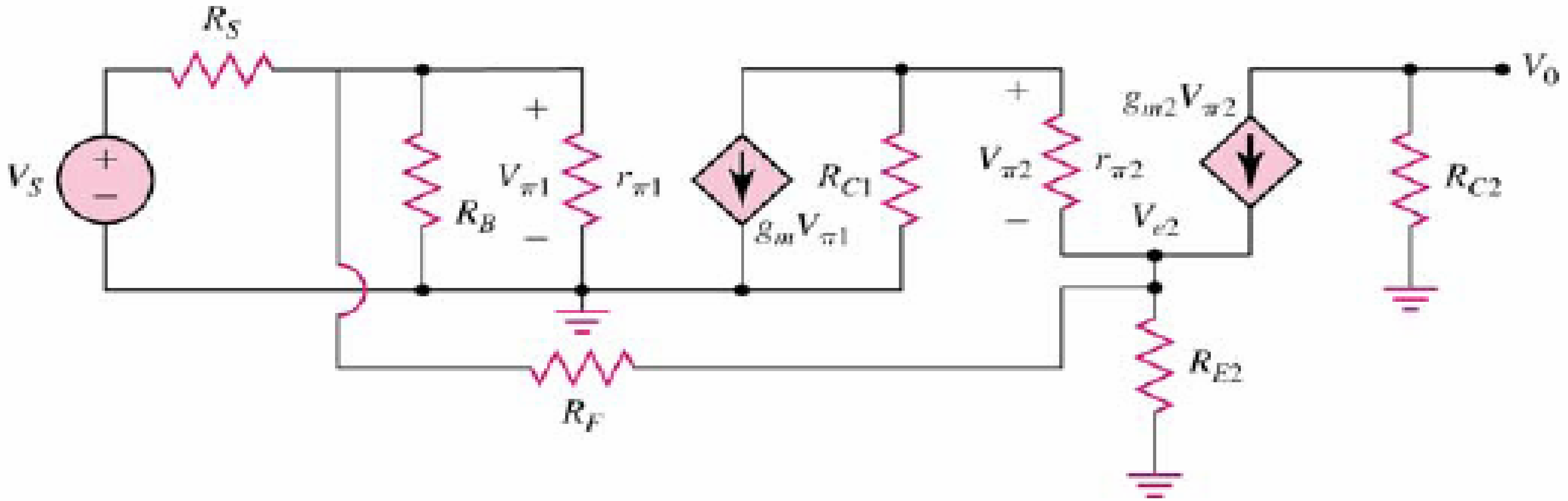
$$I_{C1} = \frac{(120)(2.606-0.7)}{9.98+(121)(1)} = 1.75 \text{ mA} \qquad V_{C1} = 10-(1.75)(3) = 4.75 \text{ V}$$

$$I_{C2} \approx \frac{4.75-0.7}{8.1} = 0.50 \text{ mA}$$

$$r_{\pi 1} = \frac{(120)(0.026)}{1.75} = 1.78 \text{ k}\Omega \qquad g_{m1} = \frac{1.75}{0.026} = 67.31 \text{ mA/V}$$

$$r_{\pi 2} = \frac{(120)(0.026)}{0.50} = 6.24 \text{ k}\Omega \qquad g_{m2} = \frac{0.50}{0.026} = 19.23 \text{ mA/V}$$

b.



$$\frac{V_S - V_{\pi 1}}{R_S} = \frac{V_{\pi 1}}{R_B \parallel r_{\pi 1}} + \frac{V_{\pi 1} - V_{e2}}{R_F} \qquad (1)$$

$$g_{m1} V_{\pi 1} + \frac{V_{\pi 2} + V_{e2}}{R_{C1}} + \frac{V_{\pi 2}}{r_{\pi 2}} = 0 \qquad (2)$$

$$\frac{V_{\pi 2}}{r_{\pi 2}} + g_{m2} V_{\pi 2} = \frac{V_{e2}}{R_{E2}} + \frac{V_{e2} - V_{\pi 1}}{R_F} \qquad (3)$$

and $V_0 = -(g_{m2} V_{\pi 2}) R_{C2}$ (4)

Substitute numerical values in (1), (2), and (3)

$$\frac{V_S}{0.6} = V_{\pi 1}\left[\frac{1}{0.6} + \frac{V_{\pi 1}}{9.98 \parallel 1.78} + \frac{1}{1.2}\right] - \frac{V_{e2}}{1.2}$$

$$V_S(1.67) = V_{\pi 1}(4.011) - V_{e2}(0.8333) \qquad (1)$$

$$(67.31)V_{\pi 1} + V_{\pi 2}\left(\frac{1}{3} + \frac{1}{6.24}\right) + \frac{V_{e2}}{3} = 0$$

$$V_{\pi 1}(67.31) + V_{\pi 2}(0.4936) + V_{e2}(0.3333) = 0 \qquad (2)$$

$$V_{\pi 1}\left(\frac{1}{6.24} + 19.23\right) = \frac{V_{e2}}{8.1} + \frac{V_{e2}}{1.2} - \frac{V_{\pi 2}}{1.2}$$

$$V_{\pi 2}(19.39) = V_{e2}(0.9568) - V_{\pi 1}(0.8333) \qquad (3)$$

From (1)

$$V_{e2} = V_{\pi 1}(4.813) - V_S(2.00)$$

Then

$$V_{\pi 1}(67.31) + V_{\pi 2}(0.4936) + (0.3333)[V_{\pi 1}(4.813) - V_S(2.00)] = 0$$

or

$$V_{\pi 1}(68.91) + V_{\pi 2}(0.4936) - V_S(0.6666) = 0 \qquad (2')$$

and

$$V_{\pi 2}(19.39) = (0.9568)\left[V_{\pi 1}(4.813) - V_S(2.00)\right] - V_{\pi 1}(0.8333)$$

or

$$V_{\pi 2}(19.39) = V_{\pi 1}(3.772) - V_S(1.914) \qquad (3')$$

We find

$$V_{\pi 1} = V_S(0.009673) - V_{\pi 2}(0.007163)$$

Then

$$V_{\pi 2}(19.39) = (3.772)[V_S(0.009673) - V_{\pi 2}(0.007163)] - V_S(1.914)$$

$$V_{\pi 2}(19.42) = V_S(-1.878) \text{ or } V_{\pi 2} = -V_S(0.09670)$$

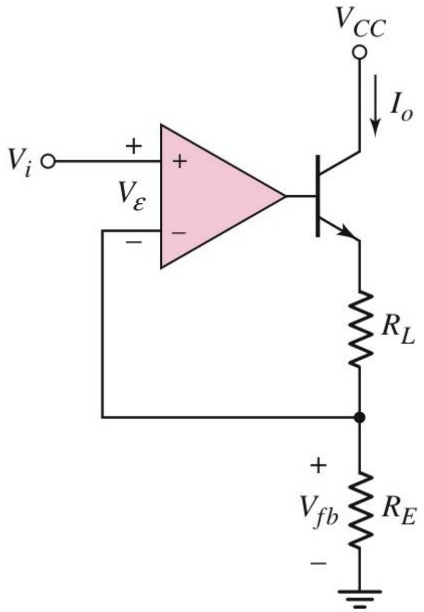
so that $V_0 = -(19.23)(4)(-V_S)(0.09670)$

Then $\underline{\dfrac{V_0}{V_S} = 7.44}$

第十二章 回授與穩定度

12.6 串-串回授組態

$$A_{gf} = \frac{I_o}{V_i} \cong \frac{1}{\beta_z}$$



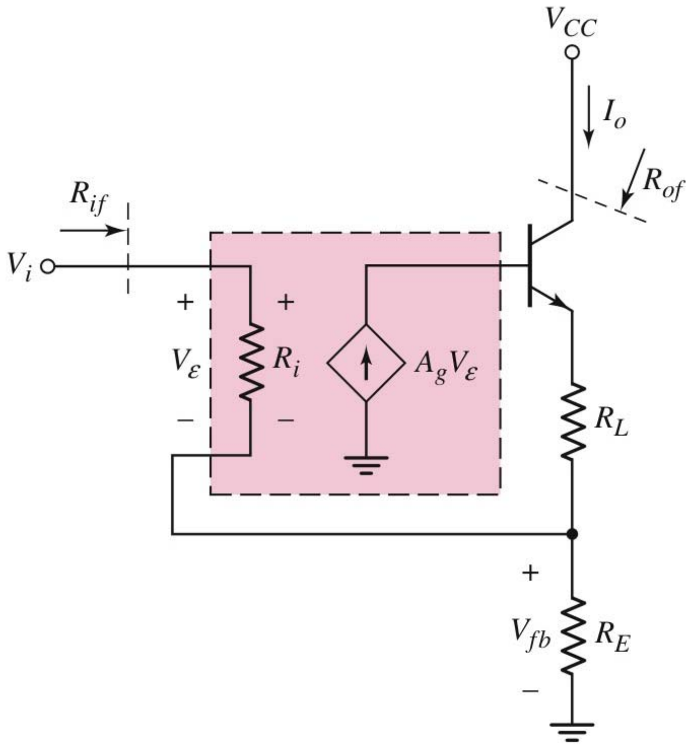
考慮放大器電路為理想的並忽略電晶體之基極電流

$$V_i = V_{fb} = I_o R_E$$

$$A_{gf} = \frac{I_o}{V_i} = \frac{1}{R_E}$$

$$\beta_z = R_E$$

第十二章 回授與穩定度



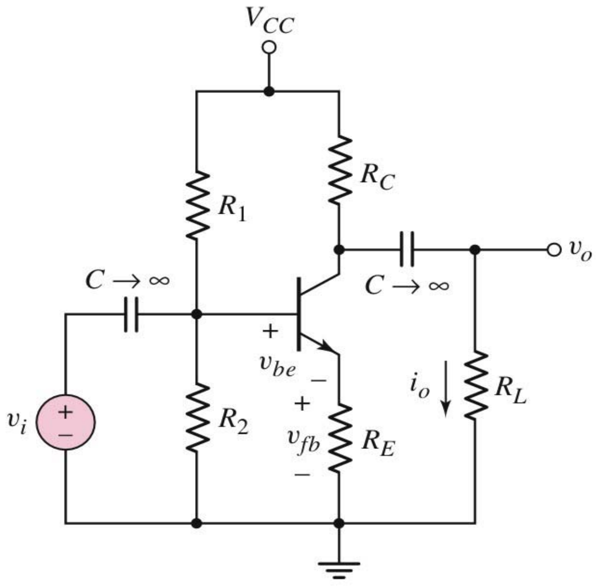
$$I_o = \frac{V_{fb}}{R_E} = h_{FE} I_b = h_{FE} A_g V_\varepsilon$$

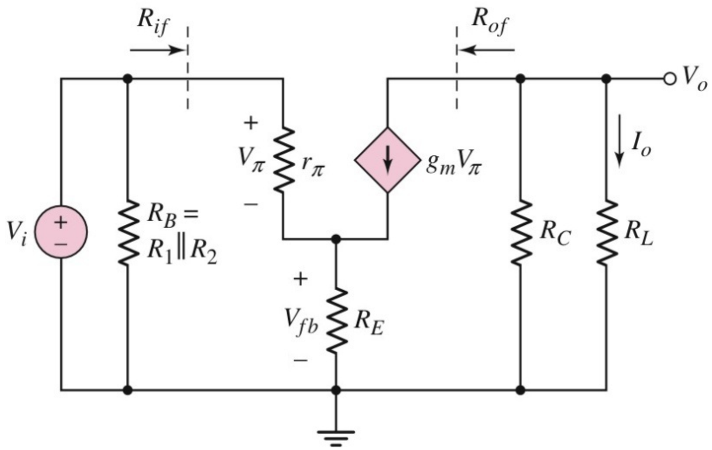
$$V_\varepsilon = V_i - V_{fb} = V_i - I_o R_E$$

$$I_o = h_{FE} A_g \left(V_i - I_o R_E \right)$$

$$A_{gf} = \frac{I_o}{V_i} = \frac{\left(h_{FE} A_g \right)}{1 + \left(h_{FE} A_g \right) R_E}$$

第十二章 回授與穩定度





$$I_o = -(g_m V_\pi)\left(\frac{R_C}{R_C + R_L}\right)$$

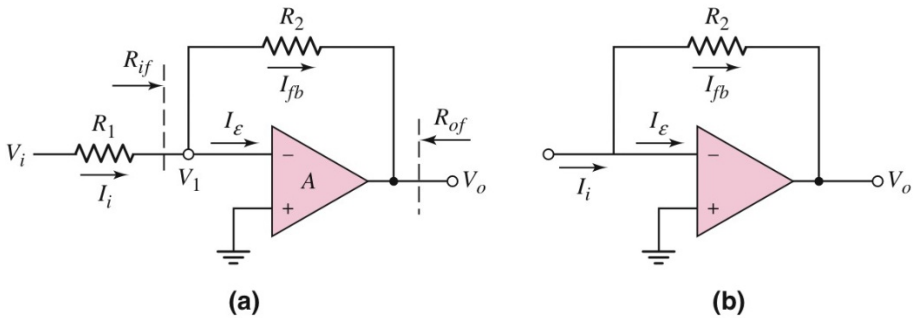
$$V_{fb} = \left(\frac{V_\pi}{r_\pi} + g_m V_\pi\right) R_E$$

$$V_i = V_\pi + V_{fb} = V_\pi\left[1 + \left(\frac{1}{r_\pi} + g_m\right) R_E\right]$$

$$A_{gf} = \frac{I_o}{V_i} = \frac{-g_m\left(\frac{R_C}{R_C + R_L}\right)}{1 + \left(\frac{1}{r_\pi} + g_m\right) R_E}$$

第十二章 回授與穩定度

12.7 並-並回授組態



$$A_{zf} = \frac{V_o}{I_i} \cong \frac{1}{\beta_g}$$

$$V_o = -I_{fb} R_2$$

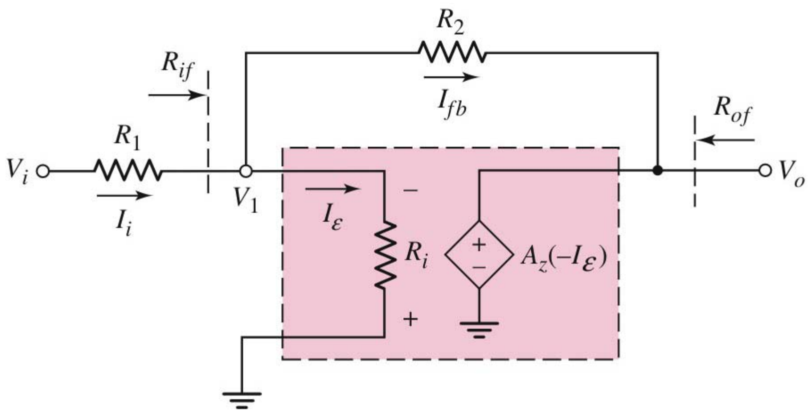
$$I_{fb} = I_i \rightarrow A_{zf} = \frac{V_o}{I_i} = -R_2$$

$$\beta_g = -\frac{1}{R_2}$$

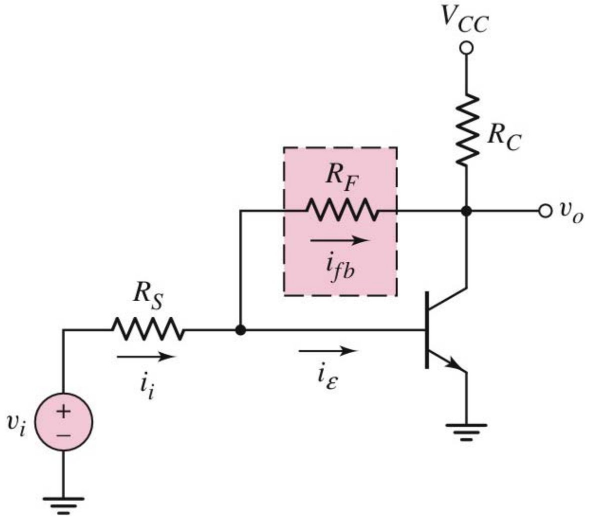
$$V_o = -A_z I_\varepsilon, \quad I_\varepsilon = I_i - I_{fb}, \quad V_o = -A_z \left(I_i - I_{fb}\right)$$

$$\rightarrow I_{fb} = -V_o / R_2$$

$$A_{zf} = \frac{V_o}{I_i} = \frac{-A_z}{\left(1 + \frac{A_z}{R_2}\right)} = \frac{-A_z}{1 + \left(-A_z\right)\beta_g}$$



第十二章 回授與穩定度



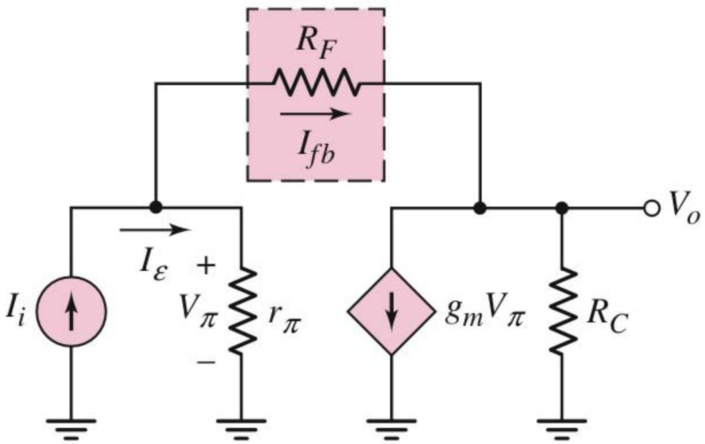
$$\frac{V_o}{R_c}+g_mV_\pi+\frac{V_o-V_\pi}{R_F}=0$$

$$I_i=\frac{V_\pi}{R_\pi}+\frac{V_\pi-V_o}{R_F}$$

$$V_o\left(\frac{1}{R_C}+\frac{1}{R_F}\right)\left(\frac{1}{r_\pi}+\frac{1}{R_F}\right)+\left(g_m-\frac{1}{R_F}\right)\left(I_i+\frac{V_o}{R_F}\right)=0$$

$$A_{zf}=\frac{V_o}{I_i}=\frac{-\left(g_m-\frac{1}{R_F}\right)}{\left(\frac{1}{R_C}+\frac{1}{R_F}\right)\left(\frac{1}{r_\pi}+\frac{1}{R_F}\right)+\frac{1}{R_F}\left(g_m-\frac{1}{R_F}\right)}$$

$$A_z=\frac{-g_m}{\left(\frac{1}{R_C}\right)\left(\frac{1}{r_\pi}\right)}=-g_mr_\pi R_C=-h_{FE}R_C$$



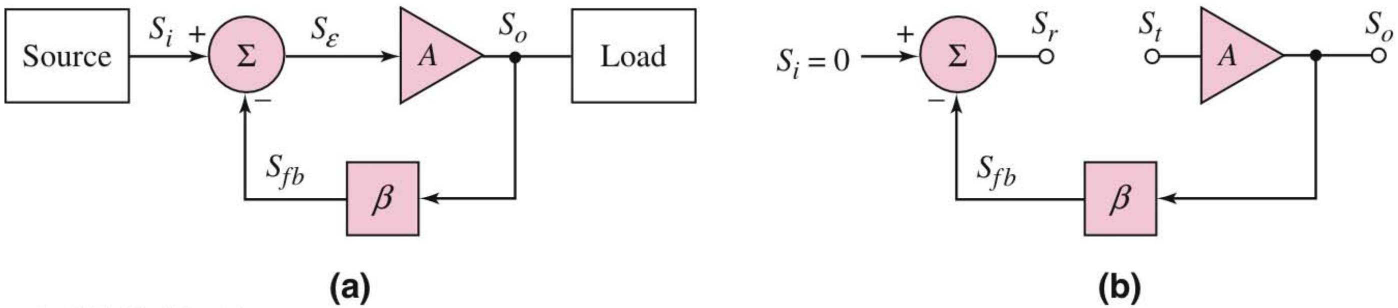
$$A_{zf}=\frac{V_o}{I_i}=\frac{+\left(A_z+\frac{r_\pi R_C}{R_F}\right)}{\left(1+\frac{R_C}{R_F}\right)\left(1+\frac{r_\pi}{R_F}\right)-\frac{1}{R_F}\left(A_z+\frac{r_\pi R_C}{R_F}\right)}$$

$$h_{FE}=g_mr_\pi\succ\succ r_\pi/R_F\,,\quad R_C\prec\prec R_F\,,\quad r_\pi\prec\prec R_F$$

$$A_{zf}=\frac{V_o}{I_i}=\frac{A_z}{1+(A_z)\left(\frac{-1}{R_F}\right)}\rightarrow\beta_g\cong\frac{-1}{R_F}$$

第十二章 回授與穩定度

12.8 迴路增益



迴路增益推導：

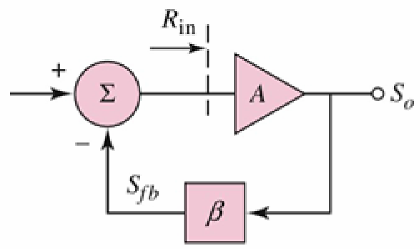
1. $S_i = 0$
2. 切斷迴路
3. 推導迴路增益

$$S_{fb} = \beta S_o = A\beta S_t$$

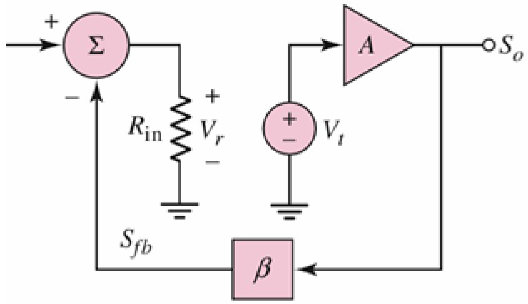
$$\frac{S_r}{S_t} = -A\beta$$

第十二章 回授與穩定度

<u>考慮切斷迴路之影響</u>



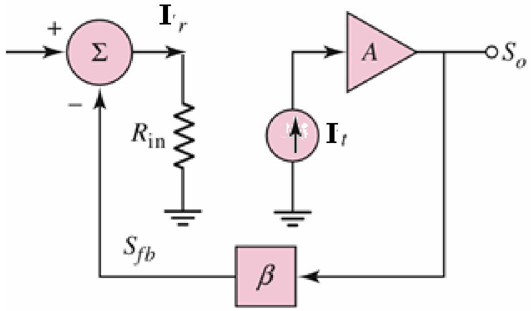
(a)



(b)

$$T = A\beta = -\frac{V_r}{V_t}$$

或

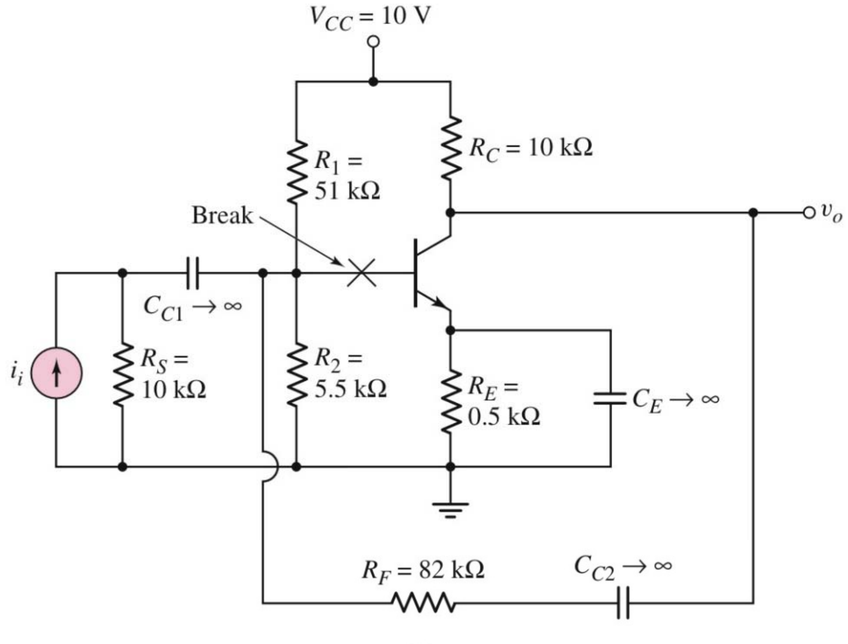


(C)

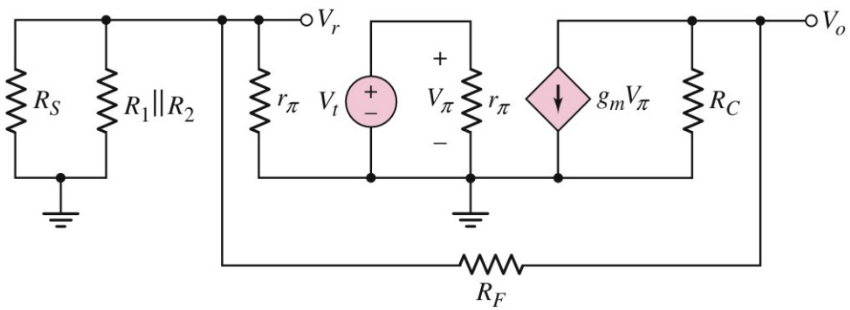
$$T = A\beta = -\frac{I_r}{I_t}$$

第十二章 回授與穩定度

例：



(a)



(b)

$I_r \rightarrow V_r = I_r r_\pi$； $I_t \rightarrow V_t = I_t r_\pi$

$$T = A\beta = -\frac{I_r}{I_t} = -\frac{V_r}{V_t}$$

$$V_O = -g_m V_t \left[R_C \parallel \left(R_F + R_{eq} \right) \right]$$

$$V_r = \left[\frac{R_{eq}}{R_F + R_{eq}} \right] V_O$$

$$T = -\frac{V_r}{V_t} = +g_m \left[\frac{R_{eq}}{R_F + R_{eq}} \right] \left[R_C \parallel \left(R_F + R_{eq} \right) \right]$$

$$R_{eq} = R_S \parallel R_1 \parallel R_2 \parallel r_\pi$$

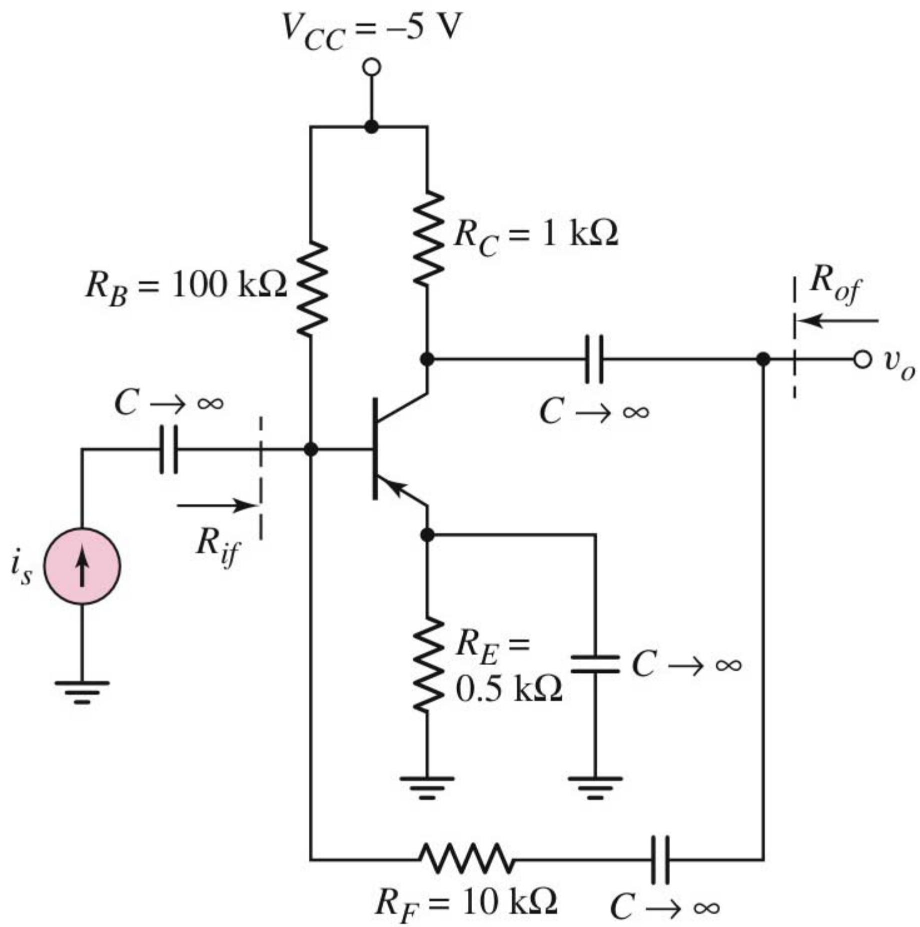
$$T = \left(g_m R_C \right) \left(\frac{R_{eq}}{R_C + R_F + R_{eq}} \right)$$

The transistor parameters for the (transresistance amplifier) circuit are:

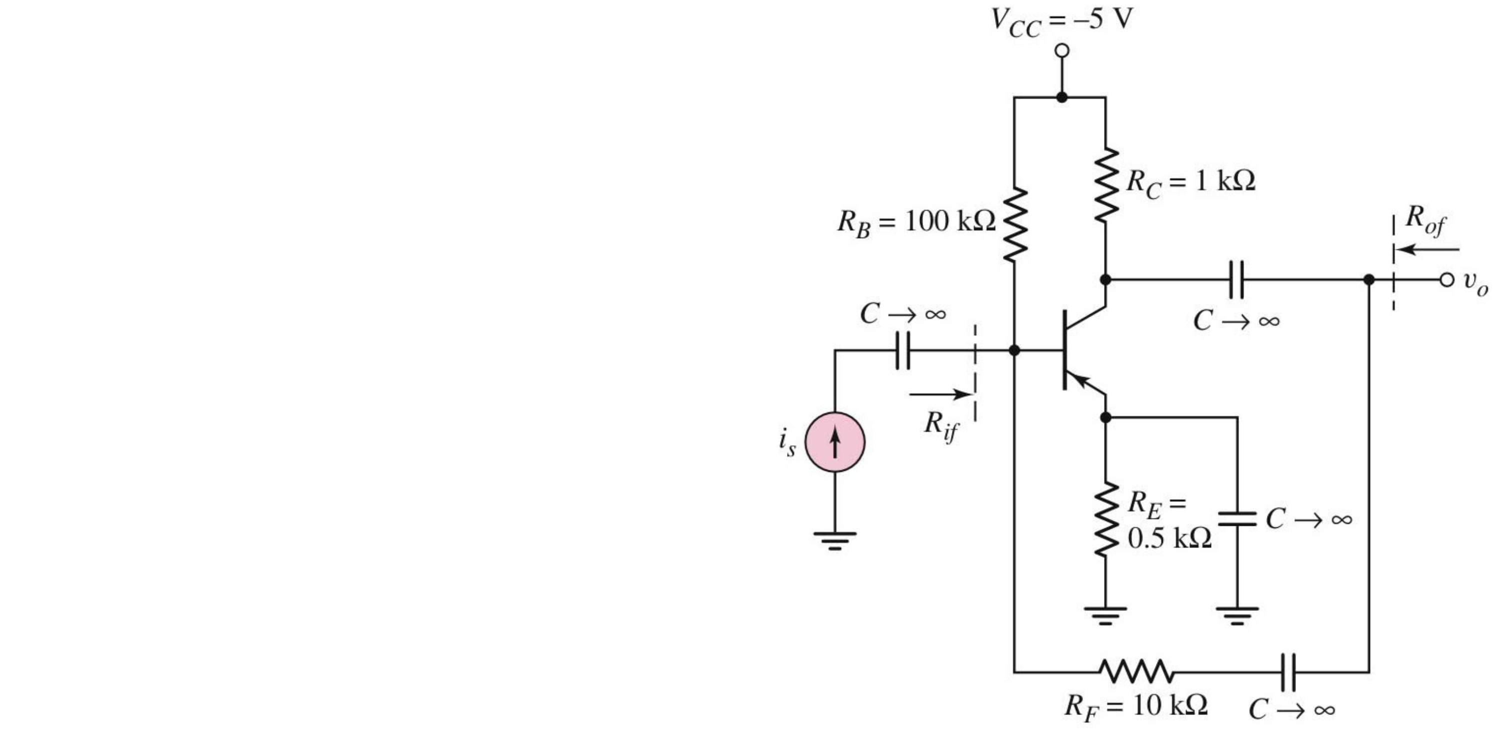
h_{FE}=80, V_{EB}=0.7V, and V_A=100V.

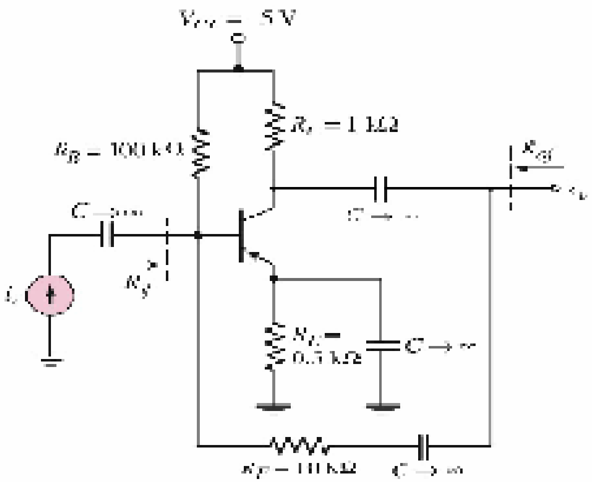
Find the loop gain T.

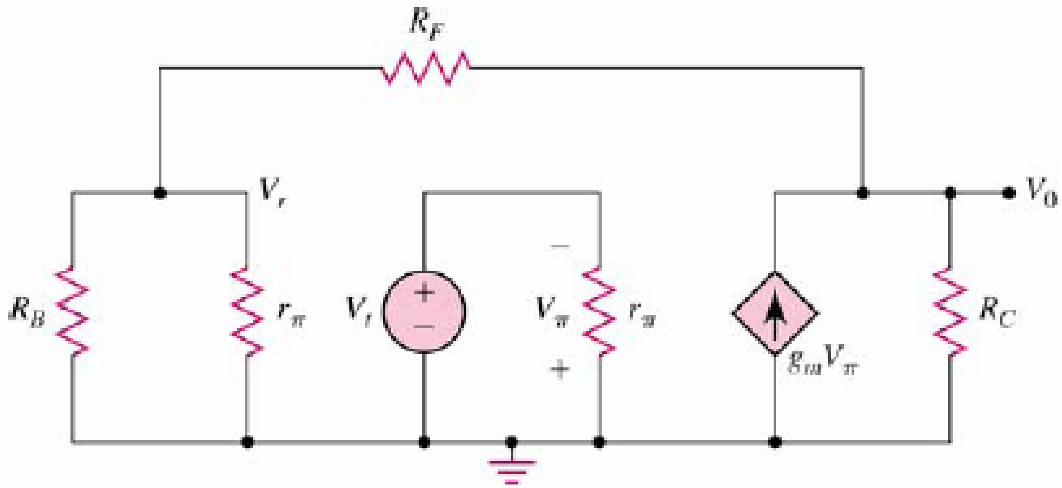
(Calculate r_π, g_m, and then T)



12.64 The transistor parameters for the circuit shown in Figure P12.54 are: →h_{FE}=50, V_{BE}=0.7V, and V_A=100V. Find the loop gain T.







dc analysis

$$I_E R_E + V_{EB}(\text{on}) + I_B R_B + V_{CC} = 0 \;\rightarrow\; I_B = \frac{5-0.7}{100+(51)(0.5)} = 0.0343\,; \quad I_C = (50)(0.0343) = 1.71 \text{ mA}$$

Then $r_\pi = \dfrac{(50)(0.026)}{1.71} = 0.760 \text{ k}\Omega\,;\quad g_m = \dfrac{1.71}{0.026} = 65.77 \text{ mA/V}$

$$V_\pi = -V_t$$

$$g_m V_\pi = \frac{V_0}{R_C} + \frac{V_0}{R_F + R_B \| r_\pi} \;\rightarrow\; (65.77)V_\pi = V_0\left(\frac{1}{1} + \frac{1}{10+100\|0.760}\right) = V_0(1.0930) \qquad (1)$$

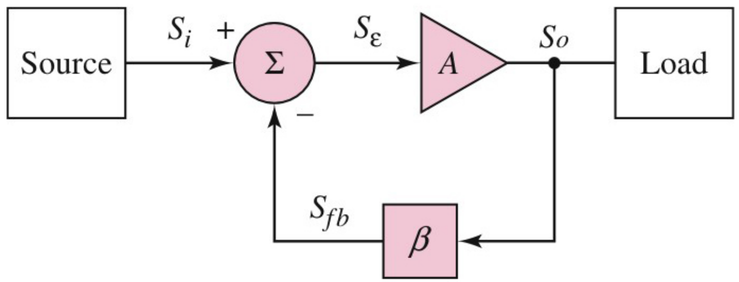
and $$V_r = \left(\frac{R_B\|r_\pi}{R_B\|r_\pi + R_F}\right)V_0 = \left(\frac{0.754}{10+0.754}\right)V_0 = (0.07011)V_0 \;\rightarrow\; V_0 = (14.26)V_r \qquad (2)$$

Then $(65.77)(-V_t) = (14.26)V_r(1.0930)$

$\dfrac{V_r}{V_t} = -4.22$ so that $\underline{T = 4.22}$

第十二章 回授與穩定度

12.9 回授放大器之穩定性



$$A_f \equiv \frac{S_o}{S_i} = \frac{A}{1+A\beta} = \frac{A}{1+T}$$

$$\rightarrow A_f(j\omega) = \frac{A(j\omega)}{1+T(j\omega)}; \quad T(j\omega) = A(j\omega)\beta(j\omega) = |T(j\omega)|\angle T(j\omega)$$

回授放大器之穩定性為迴路增益T(jω)之函數

回授放大器之穩定性：

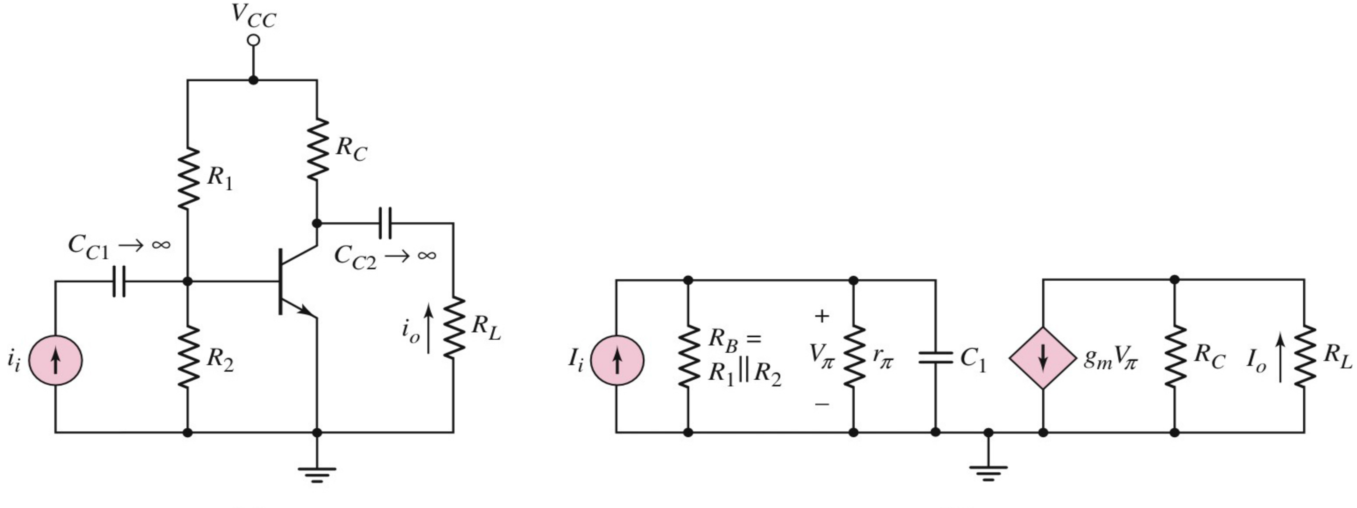
- T(jω) > -1 即 ∠T(jω)=180°時，｜T(jω)｜< 1 → 穩定 (放大器)
- T(jω)≦ -1 即 ∠T(jω)=180°時，｜T(jω)｜≧ 1 → 不穩定(振盪器)

若回授電路為電阻性電路(即β(jω)=β）
→ ∠T(jω)= ∠A(jω)

使用T(jω)的Blode plots判斷回授放大器之穩定性

第十二章 回授與穩定度

A. 放大器為簡單之單級共射極電流放大器



(a) (b)

$$I_0 = \left(\frac{R_C}{R_C + R_L}\right) g_m V_\pi \quad , \quad V_\pi = I_i \left[R_\pi \parallel \left(\frac{1}{sC_1}\right)\right] = I_i \left[\frac{R_\pi}{1 + sR_\pi C_1}\right]$$

$$\textit{where} \quad R_\pi = r_\pi \parallel R_B = r_\pi \parallel R_1 \parallel R_2$$

$$A_i = g_m R_\pi \left(\frac{R_C}{R_C + R_L}\right)\left[\frac{1}{1 + sR_\pi C_1}\right]$$

$$A_i = \frac{A_{io}}{1 + j\left(\frac{f}{f_1}\right)} = \frac{A_{io}}{\sqrt{1 + \left(\frac{f}{f_1}\right)^2}} \angle -\tan^{-1}\left(\frac{f}{f_1}\right)$$

第十二章 回授與穩定度

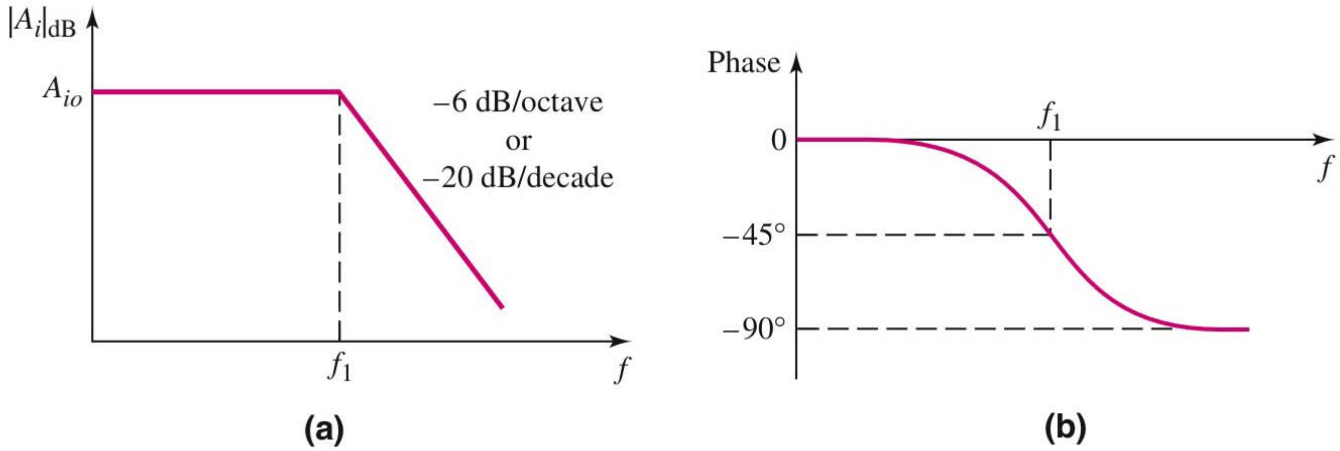


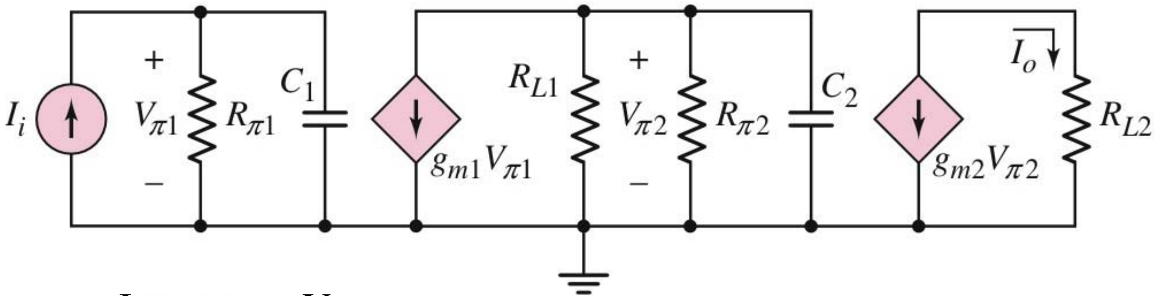
圖 **(a)** 電流增益大小之波德圖

圖 **(b)** 電流增益相位之波德圖

低頻時，輸出電流與輸入電流同相

低頻時，輸出電流與輸入電流之相位差為**90**^{O}

B. 放大器為二級放大器



二級放大器之小信號等效電路

$$I_0 = -g_{m2}V_{\pi2}$$

$$V_{\pi2} = -g_{m1}V_{\pi1}\left[R_{L1} \parallel R_{L2} \parallel \left(\frac{1}{sC_2}\right)\right]$$

$$V_{\pi1} = I_i\left[R_{\pi1} \parallel \left(\frac{1}{sC_1}\right)\right]$$

$$A_i = \frac{I_o}{I_i} = (g_{m1}g_{m2})(R_{\pi1})(R_{L1} \parallel R_{\pi2})\left[\frac{1}{1+sR_{\pi}C_1}\right]\left[\frac{1}{1+s(R_{L1} \parallel R_{\pi2})C_2}\right]$$

$$A_i = \frac{A_{io}}{\left(1+j\frac{f}{f_1}\right)\left(1+j\frac{f}{f_2}\right)}$$

$$A_i = \frac{A_{io}}{\sqrt{1+\left(\frac{f}{f_1}\right)^2}\sqrt{1+\left(\frac{f}{f_2}\right)^2}} \angle -\left[\tan^{-1}\left(\frac{f}{f_1}\right) + \tan^{-1}\left(\frac{f}{f_2}\right)\right]$$

第十二章 回授與穩定度

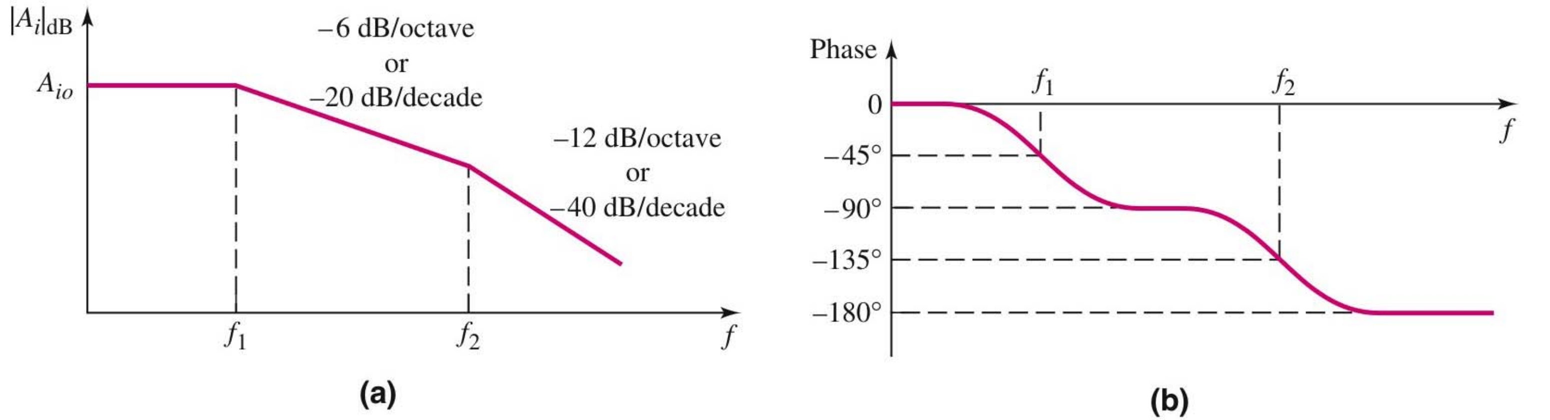


圖 **(a)**電流增益大小之波德圖

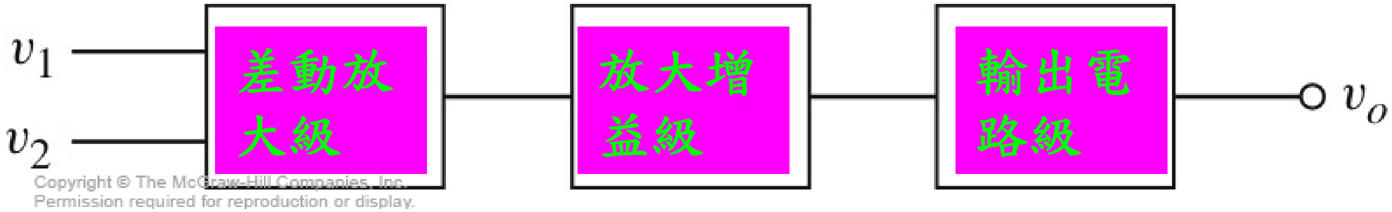
圖 **(b)**電流增益相位之波德圖

低頻時，輸出電流與輸入電流同相

低頻時，輸出電流與輸入電流之相位差為**180^{o}**

第十二章 回授與穩定度

C. 放大器三級放大器



$$A=\frac{A_o}{\left(1+j\frac{f}{f_1}\right)\left(1+j\frac{f}{f_2}\right)\left(1+j\frac{f}{f_3}\right)}$$

$$T(jw)=\beta A(jw)$$

$$T(f)=\frac{\beta A_o}{\left(1+j\frac{f}{f_1}\right)\left(1+j\frac{f}{f_2}\right)\left(1+j\frac{f}{f_3}\right)}$$

第十二章 回授與穩定度

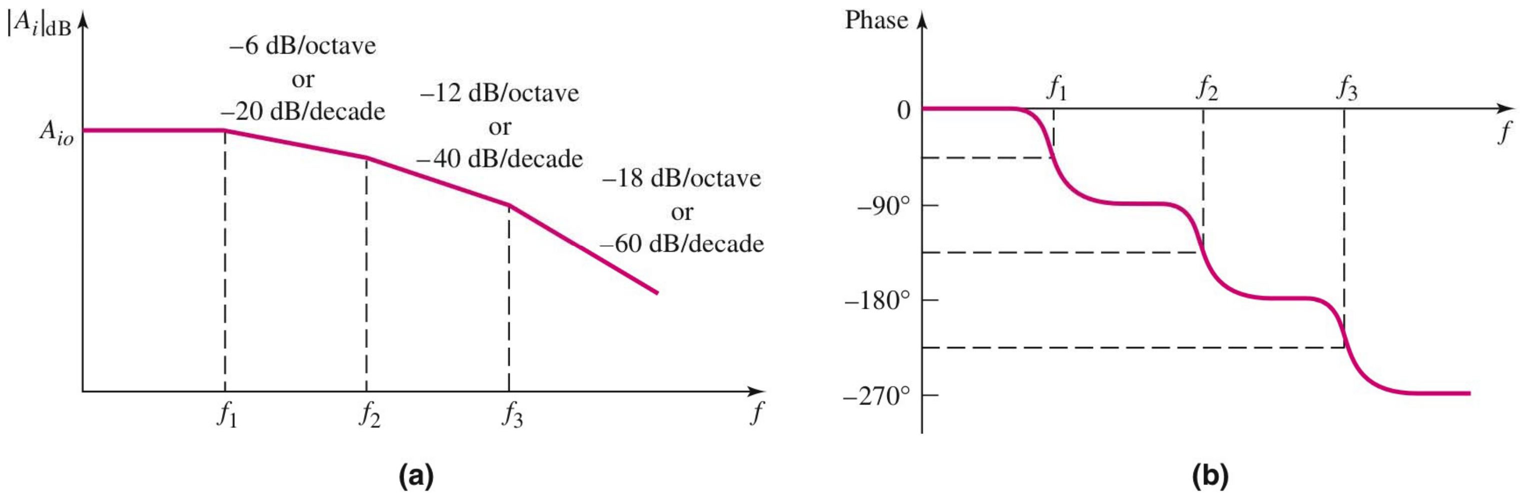


圖 **(a)**電流增益大小之波德圖

圖 **(b)**電流增益相位之波德圖

低頻時，輸出電流與輸入電流同相

低頻時，輸出電流與輸入電流之相角差為**-270^{O}**

第十二章 回授與穩定度

例： $A(f)=\dfrac{(100)}{\left(1+j\dfrac{f}{10^5}\right)^3}$； $\beta=0.2$ 及 0.02

$$\rightarrow T(f)=\frac{\beta(100)}{\left(1+j\dfrac{f}{10^5}\right)^3}=\frac{\beta(100)}{\left(\sqrt{1+\dfrac{f}{10^5}}\right)^3}\angle-3\tan^{-1}\left(\frac{f}{10^5}\right)$$

相位： $-3\tan^{-1}\left(\dfrac{f_{180}}{10^5}\right)=-180^0$

→-180度相位變之頻率 $f_{180}=1.73\times10^5\ \text{Hz}$

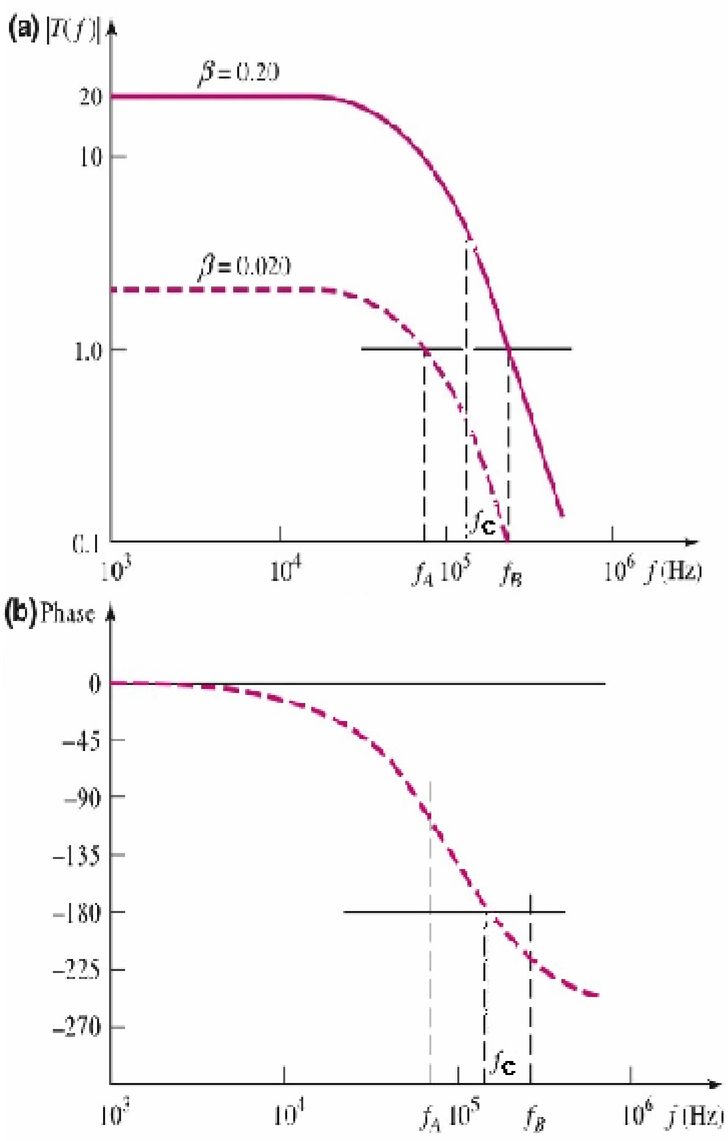
A. $\beta=0.2$

$$\left|T\left(f_{180}\right)\right|=\frac{(0.2)(100)}{8}=2.5$$ → 不穩定

B. $\beta=0.02$

$$\left|T\left(f_{180}\right)\right|=\frac{(0.02)(100)}{8}=0.25$$ → 穩定

第十二章 回授與穩定度



Blode Plots

A. $\beta = 0.02$

$|T(f_A)| = 1$；$\angle T(f_A) > -180^0$ → 穩定

即 $\angle T(f_C) = -180^0$；$|T(f_C)| < 1$

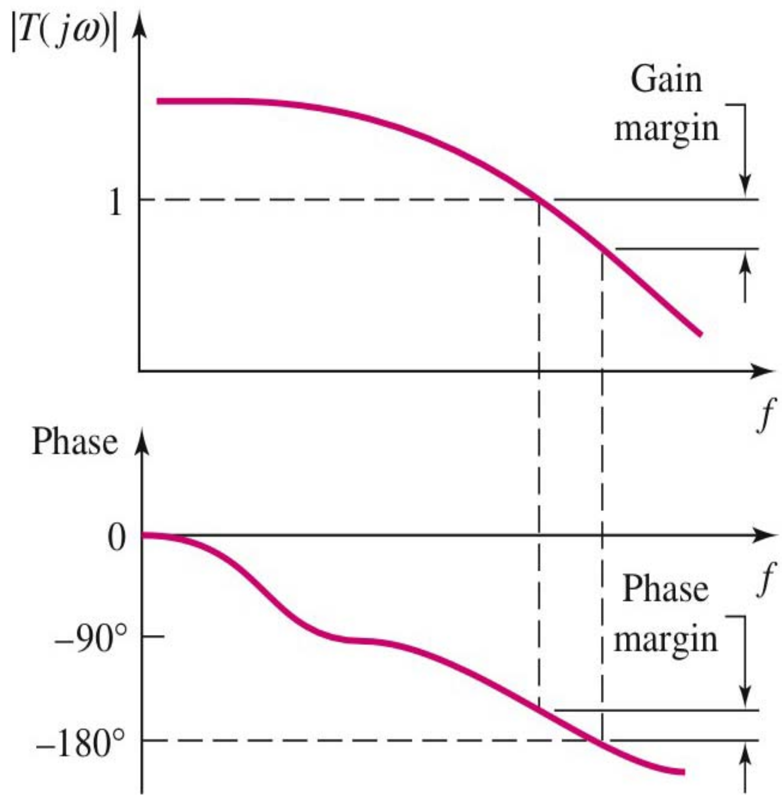
B. $\beta = 0.2$

$|T(f_B)| = 1$；$\angle T(f_B) < -180^0$ → 不穩定

即 $\angle T(f_C) = -180^0$；$|T(f_C)| > 1$

第十二章 回授與穩定度

相位邊限(phase margin)與增益邊限(gain margin):



1. 增益邊限:

當∠T(jω) = -180操作頻率時，

若 ｜T(jω)｜< 1 → 系統穩定

增益邊限 = 0 - ｜T(jω)｜(dB)

= - ｜T(jω)｜(dB)

2. 相位邊限:

當｜T(jω)｜= 1操作頻率時，

若 ∠T(jω) > -180° → 系統穩定

相位邊限 = ∠T(jω)-(- 180°)

= ∠T(jω)+ 180°

(典型所需之相位邊限落在45至60度)

12.66 The open-loop voltage gain of an amplifier is given by

$$A_v = \frac{10^3}{\left(1 + j\frac{f}{10^4}\right)^2 \left(1 + j\frac{f}{10^5}\right)}$$

(a) Assuming the feedback transfer function is not a function of frequency, determine the frequency at which the phase of the loop gain is 180 degrees. (b) At what value of β will the feedback amplifier break into oscillation? (c) Using the value of β found in part (b), what is the low-frequency closed-loop gain? (d) Is the closed-loop feedback system stable for smaller or larger values of closed-loop gain?

(a) $$T = \beta A_v = \frac{\beta(10^3)}{\left(1 + j\frac{f}{10^4}\right)^2 \left(1 + j\frac{f}{10^5}\right)}$$

$$\phi = -2\tan^{-1}\frac{f}{10^4} - \tan^{-1}\frac{f}{10^5}$$

Set $\phi = -180°$

By trial and error, $f = 4.58 \times 10^4$ Hz

(b) Set $|T| = 1$ at $f = 4.58 \times 10^4$ Hz

$$1 = \frac{\beta(10^3)}{\left(\sqrt{1 + \left(\frac{4.58 \times 10^4}{10^4}\right)^2}\right)^2 \sqrt{1 + \left(\frac{4.58 \times 10^4}{10^5}\right)^2}}$$

$$1 = \frac{\beta(10^3)}{(21.976)(1.10)} \Rightarrow \beta = 0.02417$$

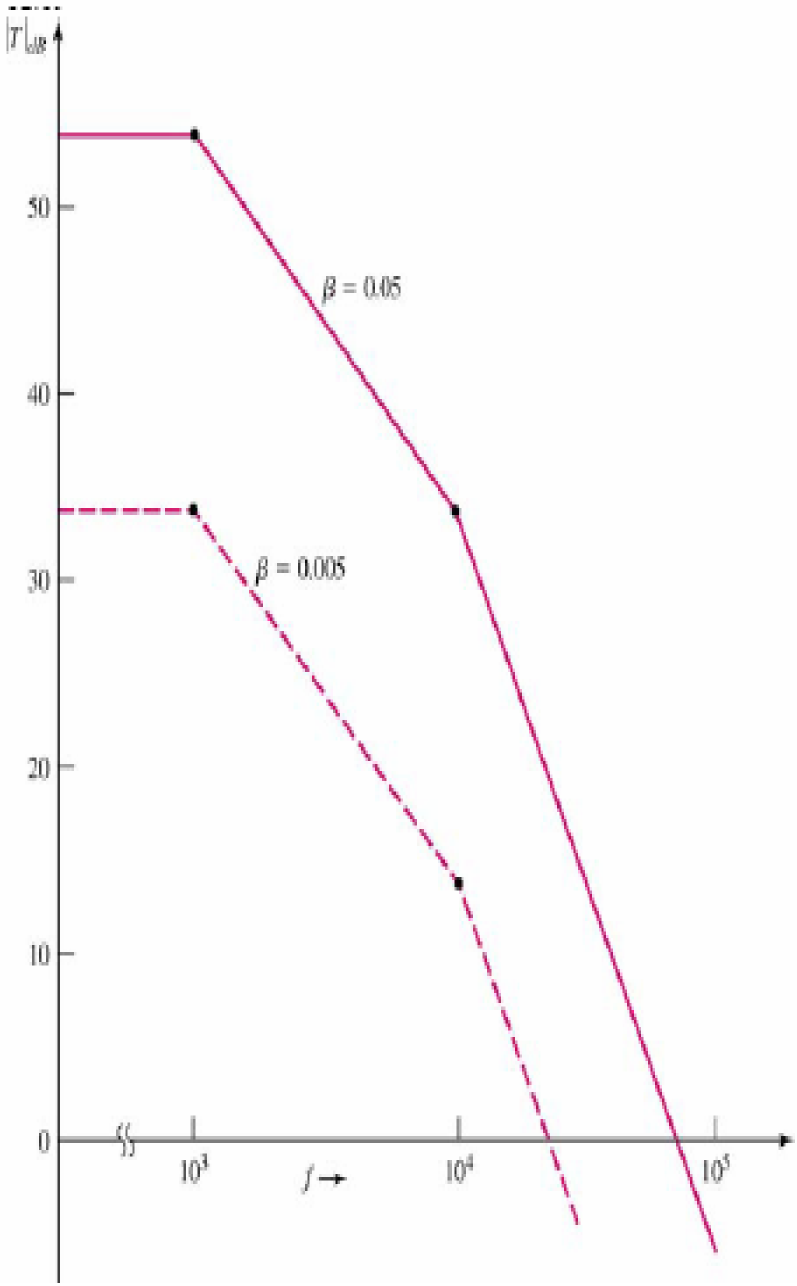
(c) $$A_{vf_o} = \frac{10^3}{1 + (10^3)(0.02417)} = 39.7$$

(d) Wait $|T| < 1$ at $f = 4.58 \times 10^4$ Hz, so system is stable for smaller values of β.

10.69 A three pole feedback amplifier has a loop gain given by

$$T(f) = \frac{\beta(10^4)}{\left(1 + j\frac{f}{10^3}\right)\left(1 + j\frac{f}{10^4}\right)\left(1 + j\frac{f}{10^5}\right)}$$

Sketch Bode Plots of the loop gain magnitude and phase for (a) β =0.005, and (b) β =0.05. (c) Is the system stable or unstable in each case? If the system is stable, what is the phase margin?



c. For $\beta = 0.005$,

$\left|T(f)\right| = 1(0\text{ dB})$ at $f \approx 2.10\times10^4$ Hz

Then

$$\phi = -\tan^{-1}\left(\frac{2.10\times10^4}{10^3}\right) - \tan^{-1}\left(\frac{2.10\times10^4}{10^4}\right) - \tan^{-1}\left(\frac{2.10\times10^4}{10^5}\right)$$

$$= -87.27 - 64.54 - 11.86 = -163.7$$

System is stable. Phase margin $= 16.3°$

For $\beta = 0.05$,

$\left|T(f)\right| = 1\ (0\text{ dB})$ at $f \approx 6.44\times10^4$ Hz

Then

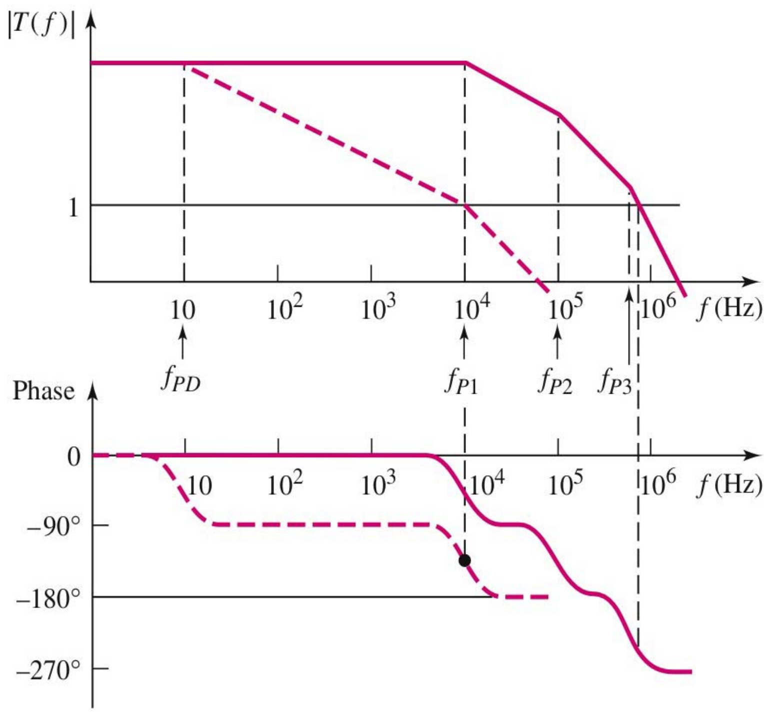
$$\phi = -\tan^{-1}\left(\frac{6.44\times10^4}{10^3}\right) - \tan^{-1}\left(\frac{6.44\times10^4}{10^4}\right) - \tan^{-1}\left(\frac{6.44\times10^4}{10^5}\right)$$

$$= -89.11 - 81.17 - 32.78 = -203.1° \Rightarrow \text{System is unstable.}$$

第十二章 回授與穩定度

12.10 頻率補償

A. 引入新極點



1. 在回路增益中引入一個頻率很低的新極點 f_{PD}
   → 致 $|T(f)| = 1$時，使$|\phi(f)| < 180°$。

2. 在引入新極點 f_{PD} 時，假設原始的三個極點不會變動
   → 新的回路增益大小與相位波德圖將如圖中之虛線所示。

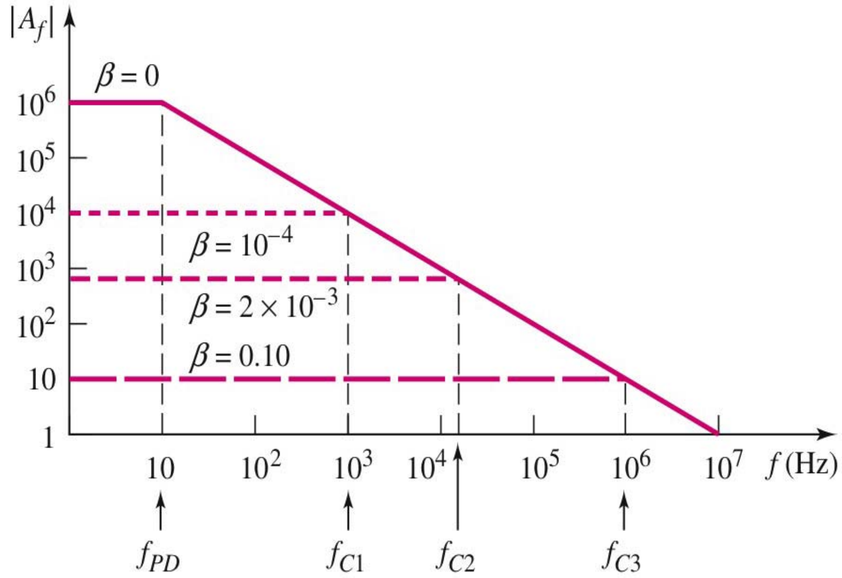
第十二章 回授與穩定度

$$A(f) = \frac{A_o}{1 + j\frac{f}{f_{PD}}}$$

$$A_f(f) = \frac{A(f)}{(1 + \beta A(f))}$$

$$A_f(f) = \frac{A_o}{(1 + \beta A_o)} \times \frac{1}{1 + j\frac{f}{f_{PD}(1 + \beta A_o)}}$$

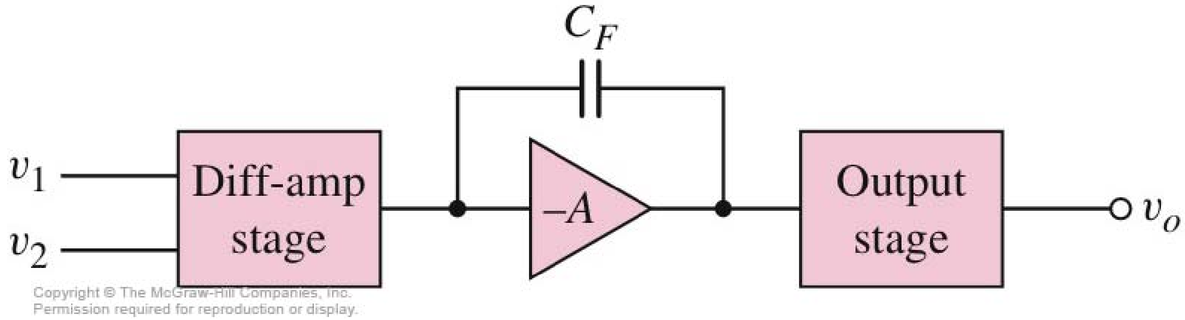
$$= \frac{A_{fo}}{1 + j\frac{f}{f_{fPD}}}$$



where $A_{fo} = \frac{A_o}{(1 + \beta A_o)}$; $f_{fPD} = f_{PD}(1 + \beta A_o)$

and $A_{fo} \times f_{fPD} = A_o \times f_{PD}$

B. 米勒補償技術

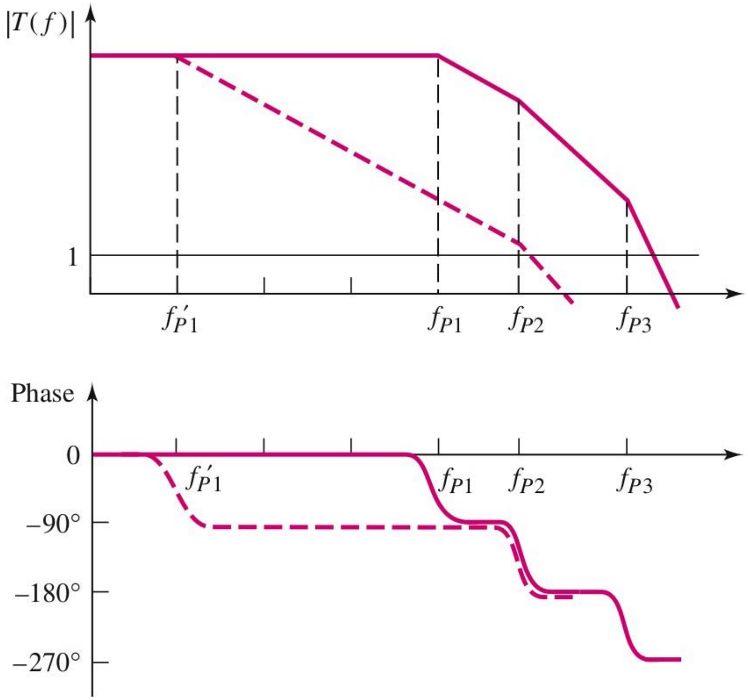


C_F 稱為補償電容

$$C_M = C_F(1 + A)$$

$$f_{P1} = \frac{1}{2\pi R_2 C_M}$$

第十二章 回授與穩定度



1. 米勒補償技術**:**

移動極點 $f_{P1} \rightarrow f_{P1}'$

2. 在移動極點 f_{P1}時，
假設其它兩個極點不會變動
→使得 **|T(f)|=1** 之頻率較低，
且 **|ø| > -180^0 (**放大器穩定**)** 。

12.77 A loop gain function is given by

$$T(f) = \frac{500}{\left(1 + j\frac{f}{10^4}\right)\left(1 + j\frac{f}{5x10^4}\right)\left(1 + j\frac{f}{10^5}\right)}$$

(a) Determine the frequency f_{180} (to a good approximation) at which the phase of T(f) is -180°. (b) What is the magnitude of T(f) at the frequency f= f_{180} found in part (a)? (c) Insert a dominant pole such that the phase margin is approximately 60°. Assume the original poles are fixed. What is the dominant pole frequency?

(a) $$\phi = -180 = -\tan^{-1}\left(\frac{f_{180}}{10^4}\right) - \tan^{-1}\left(\frac{f_{180}}{5\times10^4}\right) - \tan^{-1}\left(\frac{f_{180}}{10^5}\right)$$

$f_{180} \cong 8.06\times10^4$ Hz

(b) $$|T| = \frac{500}{\sqrt{1+\left(\frac{8.06\times10^4}{10^4}\right)^2}\sqrt{1+\left(\frac{8.06\times10^4}{5\times10^4}\right)^2}\sqrt{1+\left(\frac{8.06\times10^4}{10^5}\right)^2}}$$

$$= \frac{500}{(8.122)(1.897)(1.284)} = 25.3$$

(c) $$T = \frac{500}{\left(1+j\frac{f}{f_{PD}}\right)\left(1+j\frac{f}{10^4}\right)\left(1+j\frac{f}{5\times10^4}\right)\left(1+j\frac{f}{10^5}\right)}$$

Phase Margin $= 60° \Rightarrow \phi = -120° = -\tan^{-1}\frac{f}{f_{PD}} - \tan^{-1}\frac{f}{10^4} - \tan^{-1}\frac{f}{5\times10^4} - \tan^{-1}\frac{f}{10^5}$

Assume $\tan^{-1}\frac{f}{f_{PD}} \cong 90°$ Then $f \cong 4.2\times10^3$ Hz

$$|T| = 1 = \frac{500}{\sqrt{1+\left(\frac{4.2\times10^3}{f_{PD}}\right)^2}\sqrt{1+\left(\frac{4.2\times10^3}{10^4}\right)^2}\sqrt{1+\left(\frac{4.2\times10^3}{5\times10^4}\right)^2}\sqrt{1+\left(\frac{4.2\times10^3}{10^5}\right)^2}}$$

$$1 = \frac{500}{\sqrt{1+\left(\frac{4.2\times10^3}{f_{PD}}\right)^2}(1.085)(1.004)(1.0)}$$

$$\frac{4.2\times10^3}{f_{PD}} \cong \frac{500}{(1.0846)(1.0035)(1.0)}$$

$f_{PD} = 9.14$ Hz