Lecture 30

Feedback amplifier

Lecture Feedback Amplifier

- Negative Feedback
- Feedback Topology
- Analysis of feedback applications
  - Close-Loop Gain
  - Input/Output resistances

Input/Output Resistance (Series-Series)

Input Resistance:

$$R_{\text{in}} = \frac{V_i}{I_i}$$

$$= \frac{(1+T)\cdot V_\varepsilon}{I_i}$$

$$= (1+T)\cdot r_i$$

Output Resistance
(Closed loop output resistance with zero input voltage)

$$R_{\text{out}}\,|_{V_i=0} = \frac{V_o}{I_o}$$

from input port,

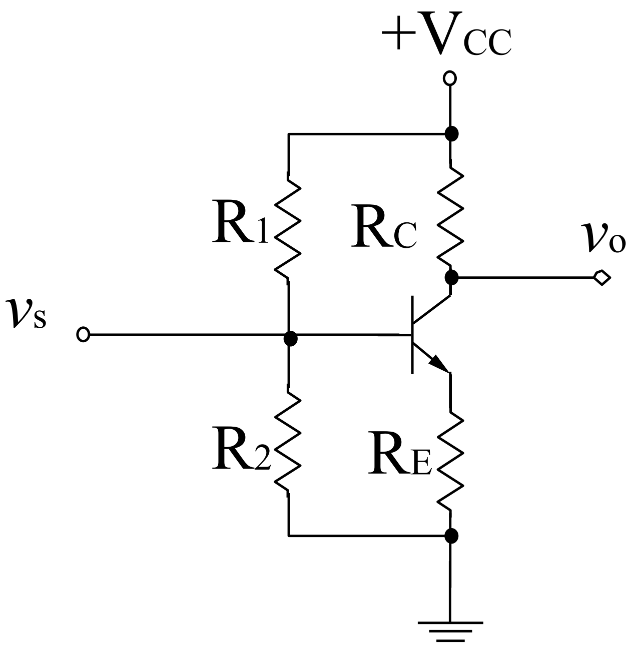
$$V_\varepsilon = V_f = -\beta \cdot I_o$$

from output port,

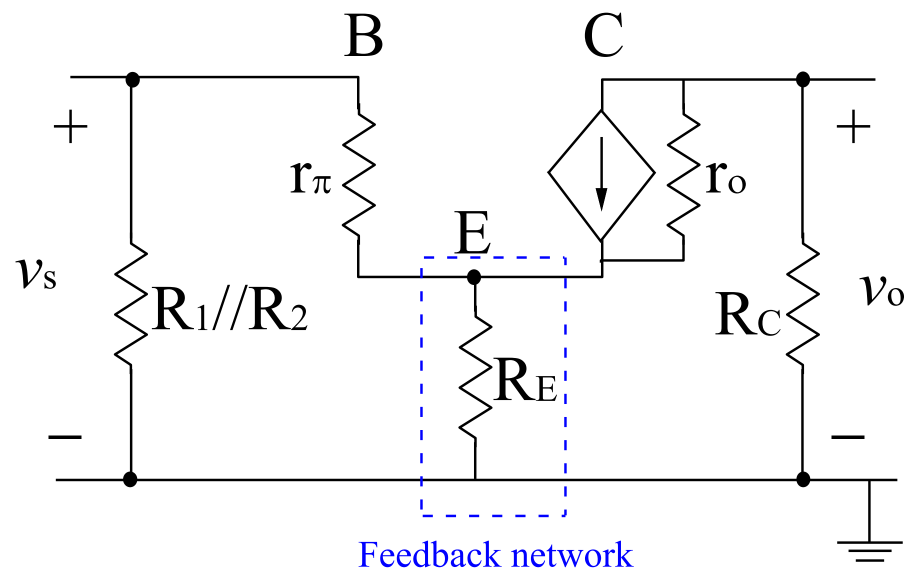
$$I_o = AV_\varepsilon + \frac{V_o}{r_o} = -T\cdot I_o + \frac{V_o}{r_o}$$

$$\Rightarrow R_{\text{out}} = \frac{V_o}{I_o} = (1+T)r_o$$

Series-Series Example



CE amplifier with an un-bypassed emitter



ac small signal equivalent circuit

Close loop analysis

$$v_\pi = \left(\frac{r_\pi}{r_\pi + Z_{11f}} \right) v_s \text{ and } i_o = g v_\pi$$

Then open loop transadmittance gain is $A_{op} = \frac{i_o}{v_s} = \frac{r_\pi g}{r_\pi + R_E}$

Therefore,

The close loop transadmittance gain is $A_{CL} = \frac{A_{op}}{1 + A_{op}\beta} = \frac{\frac{r_\pi g}{r_\pi + R_E}}{1 + \frac{r_\pi g R_E}{r_\pi + R_E}} = \frac{r_\pi g}{r_\pi + R_E + r_\pi g R_E}$

Input impedance is :

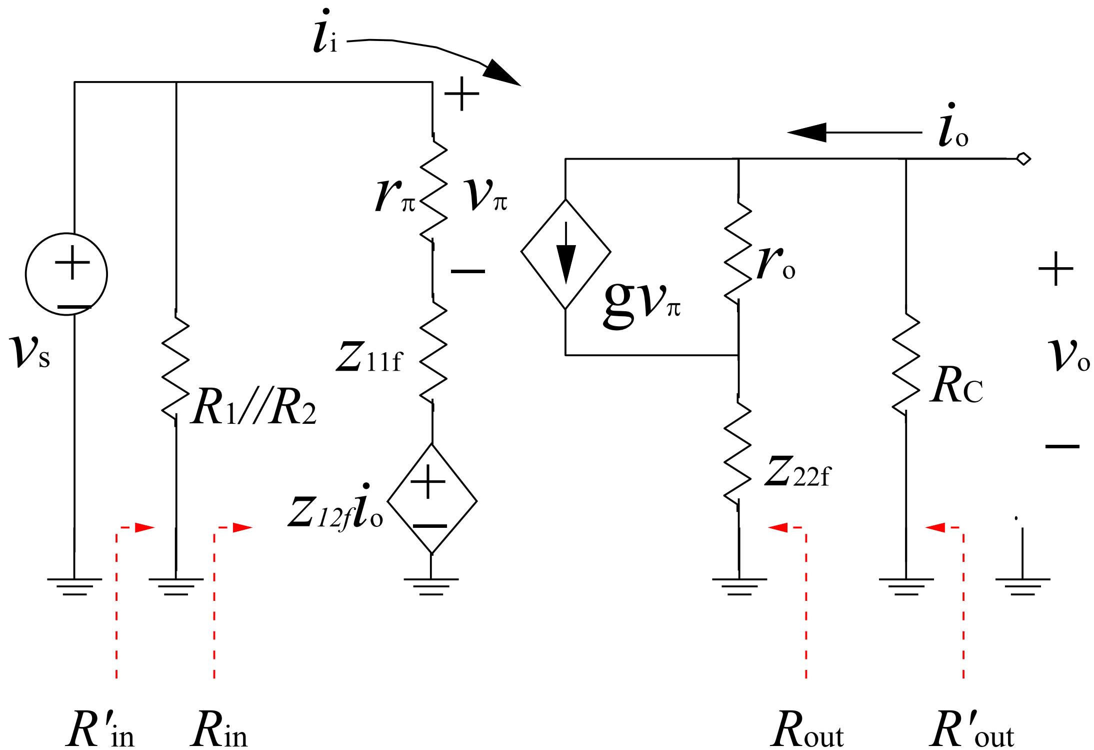
$$\mathrm{R_{in}} = (r_\pi + z_{11f})(1 + A_{OL}\beta) = (r_\pi + R_E)\left(1 + \frac{r_\pi g R_E}{(r_\pi + R_E)}\right)$$

$$= (r_\pi + R_E) + g r_\pi R_E$$

Output impedance is :

$$\mathrm{R_{out}} = [(z_{22f})(1 + A_{OL}\beta)]$$

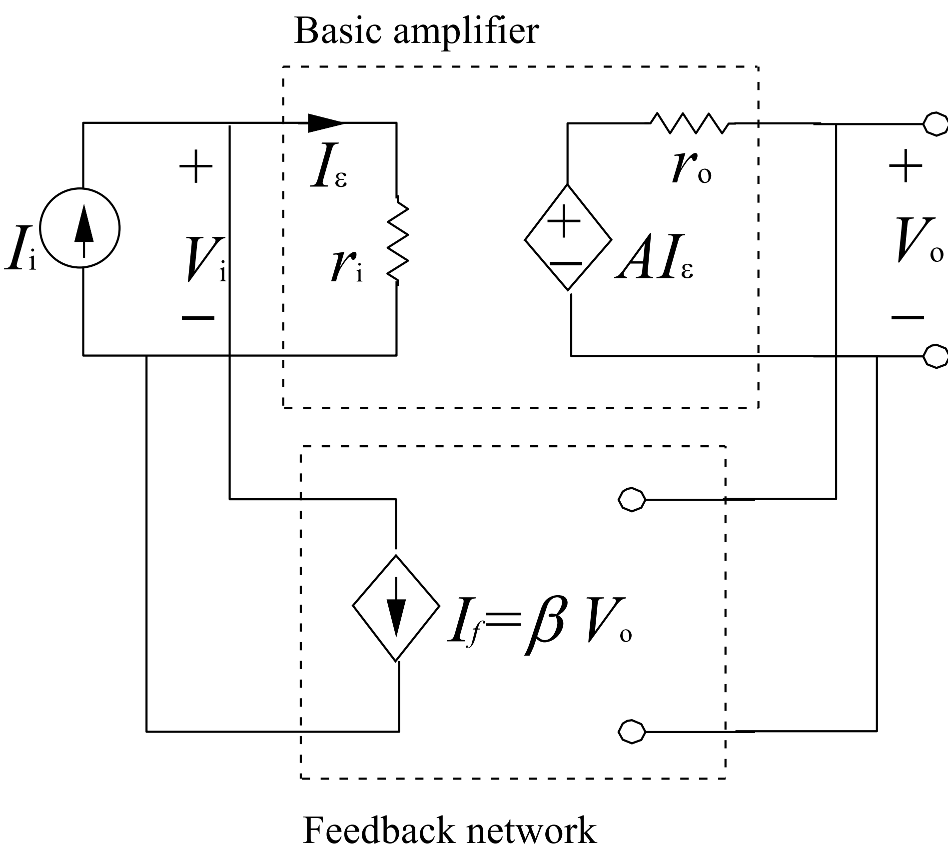
Final R_{in} and R_{out}



$$R'_{in} = R_{in} \,//\, R_1 \,//\, R_2$$
$$= [(r_\pi + R_E) + g r_\pi R_E] \,//\, R_1 \,//\, R_2$$

$$R'_{out} = R_{out} \,//\, R_C$$
$$= [(z_{22f})(1 + A_{OP}\beta)] \,//\, R_C$$

Feedback Structure (Shunt-Shunt)



Gain Calculation :

$$V_o = A \cdot I_\varepsilon = A(I_i - I_f)$$

$$I_f = \beta \cdot V_o$$

$$A(I_i - \beta V_o) = V_o$$

$$AI_i = (1+T)V_o$$

(Close Loop Transimpedance Gain)

$$\Rightarrow A_{CL} = \frac{V_o}{I_i} = \frac{1}{\beta}\left(\frac{T}{1+T}\right)$$

where $T = A\beta$

And, we get

$$V_o = \frac{I_i \cdot A}{1 + A \cdot \beta}$$

$$I_i = I_\varepsilon (1 + A \cdot \beta)$$

Input/Output Resistance (Shunt-Shunt)

Input Resistance:

$$R_{\text{in}} = \frac{V_i}{I_i}$$

$$= \frac{I_\varepsilon \cdot r_i}{I_\varepsilon (1+T)}$$

$$= \frac{r_i}{(1+T)}$$

Output Resistance

(Closed loop output resistance with zero input voltage)

$$R_{\text{out}} |_{V_i=0} = \frac{V_o}{I_o}$$

from input port,

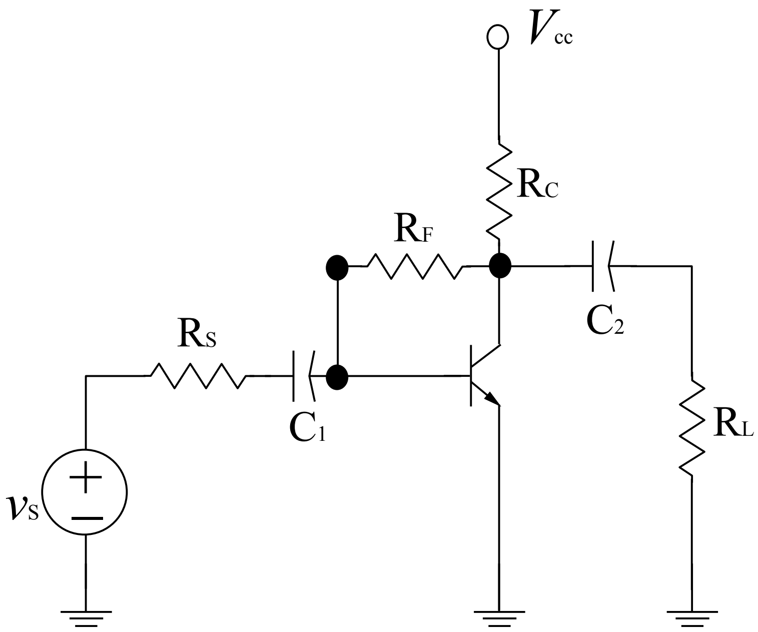
$$I_\varepsilon = -I_f = -\beta V_o$$

from output port,

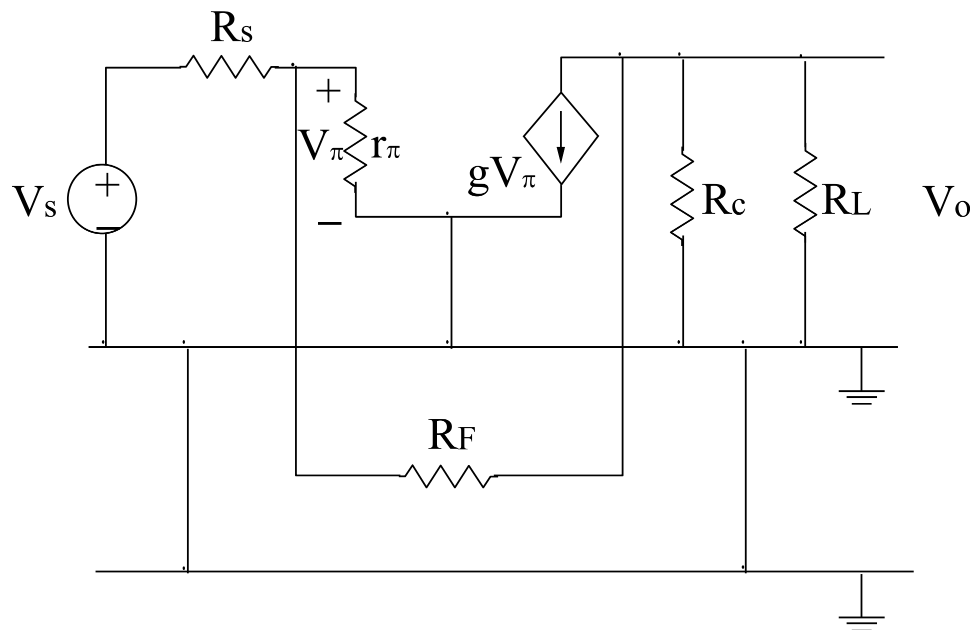
$$I_o = \frac{V_o - AI_\varepsilon}{r_o} = \frac{V_o + TV_o}{r_o}$$

$$\Rightarrow R_{\text{out}} = \frac{V_o}{I_o} = \frac{r_o}{(1+T)}$$

Shunt-Shunt Example



CE amplifier



ac small signal equivalent circuit

Shunt-Shunt connection found! ⇒ y-parameter

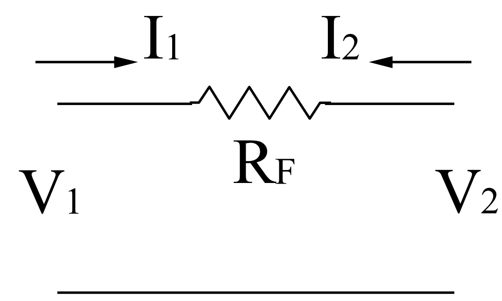
$$I_1 = y_{11}V_1 + y_{12}V_2$$

$$I_2 = y_{21}V_1 + y_{22}V_2$$

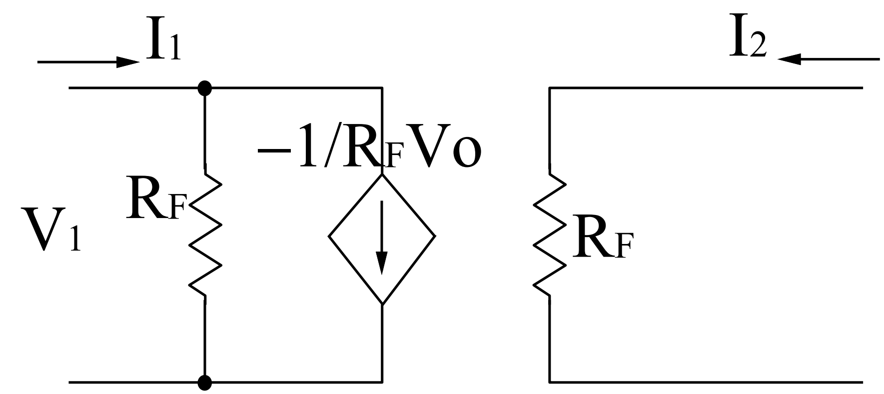
$$y_{11} = \left.\frac{I_1}{V_1}\right|_{V_2=0} = \frac{1}{R_F}$$

$$y_{12} = \left.\frac{I_1}{V_2}\right|_{V_1=0} = \frac{-I_2}{V_2} = -\frac{1}{R_F}$$

$$y_{22} = \left.\frac{I_2}{V_2}\right|_{V_1=0} = \frac{1}{R_F}$$



Feedback Network

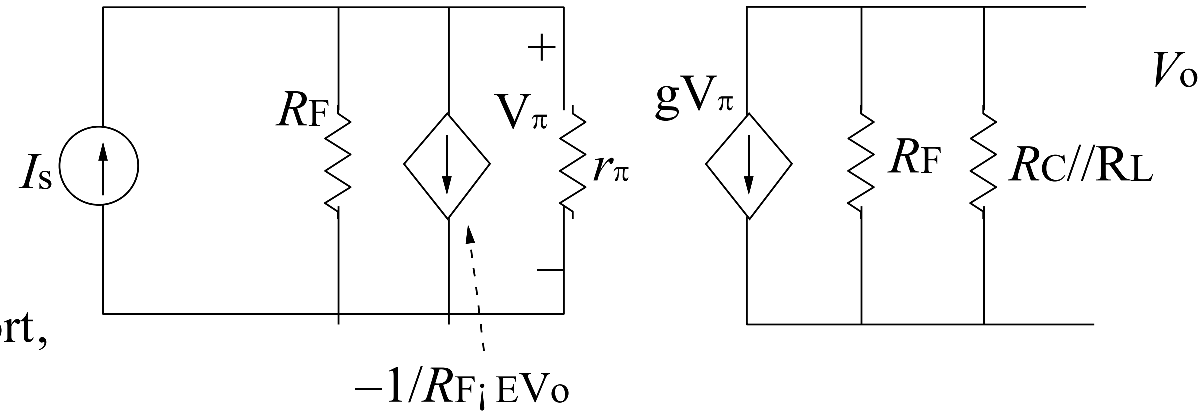


y-parameter modeling

From input port,

$$V_\pi = I_S (R_F // r_\pi)$$

$$\Rightarrow I_S = \frac{V_\pi}{(R_F // r_\pi)}$$



And from output port,

$$\frac{V_o}{R_F // R_C // R_L} + gV_\pi = 0$$

$$V_o = -gV_\pi (R_F // R_C // R_L)$$

Open loop tranimpedance gain : $\frac{V_o}{I_S}$

$$A_{OP} = -gV_\pi (R_F // R_C // R_L)(R_F // r_\pi)$$

With feedback factor $\beta = -\frac{1}{R_F}$,

the close loop transimpedance gain :

$$A_{CL} = \frac{A_{OP}}{1 + A_{OP}\beta}$$

$$R_{\text{in}} = \frac{r_i}{(1 + A_{OP}\beta)}$$

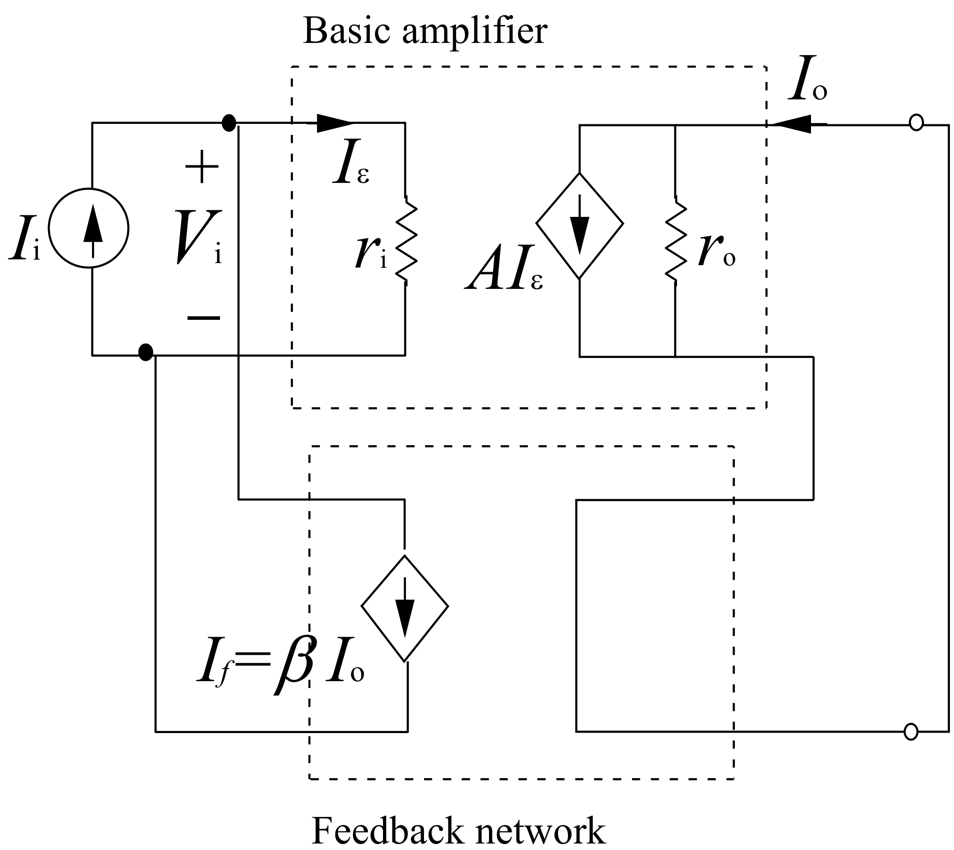
$$= \frac{(R_F // r_\pi)}{(1 + A_{OP}\beta)}$$

$$R_{\text{out}} = \frac{r_o}{(1 + A_{OP}\beta)}$$

$$= \frac{(R_F // R_C // R_L)}{(1 + A_{OP}\beta)}$$

Voltage Gain : $\frac{V_o}{V_s} = \frac{V_o}{I_s (R_s + R_{in})}$

Feedback Structure (Shunt-Series)



Gain Calculation :

$$I_o = A \cdot I_\varepsilon = A(I_i - I_f)$$

$$I_f = \beta \cdot I_o$$

$$A(I_i - \beta I_o) = I_o$$

$$AI_i = (1+T)I_o$$

(Close Loop Current Gain)

$$\Rightarrow A_{CL} = \frac{I_o}{I_i} = \frac{1}{\beta}\left(\frac{T}{1+T}\right)$$

where $T = A\beta$

And, we get

$$I_o = \frac{I_i \cdot A}{1 + A \cdot \beta}$$

$$I_i = I_\varepsilon (1 + A \cdot \beta)$$

Input/Output Resistance (Shunt-Series)

Input Resistance:

$$R_{\text{in}} = \frac{V_i}{I_i} = \frac{I_\varepsilon r_i}{I_i}$$

$$= \frac{\frac{I_i}{(1+T)} \cdot r_i}{I_i}$$

$$= \frac{r_i}{(1+T)}$$

Output Resistance
(Closed loop output resistance with zero input voltage)

$$R_{\text{out}}\big|_{V_i=0} = \frac{V_o}{I_o}$$

from input port,

$$I_\varepsilon = -I_f = -\beta I_o$$

from output port, $I_o = V_o / r_o + A I_\varepsilon$

$$V_o = (I_o - A I_\varepsilon) r_o$$

$$V_o = (I_o + T \cdot I_o) r_o$$

$$\Rightarrow R_{\text{out}} = \frac{V_o}{I_o} = (1+T) r_o$$

Summary

Feedback Structure	Close loop gain	Input impedance	Output impedance	Parameter used
Series-Shunt	$\frac{V_o}{V_i} = \frac{1}{\beta}(\frac{T}{1+T})$	$R_{\text{in}} = (1+T)\cdot r_i$	$R_{\text{out}} = \frac{r_o}{1+T}$	h-parameter
Series-Series	$\frac{I_o}{V_i} = \frac{1}{\beta}(\frac{T}{1+T})$	$R_{\text{in}} = (1+T)\cdot r_i$	$R_{\text{out}} = (1+T)\cdot r_o$	z-parameter
Shunt-Shun	$\frac{V_o}{I_i} = \frac{1}{\beta}(\frac{T}{1+T})$	$R_{\text{in}} = \frac{r_i}{1+T}$	$R_{\text{out}} = \frac{r_o}{1+T}$	y-parameter
Shunt-Series	$\frac{I_o}{I_i} = \frac{1}{\beta}(\frac{T}{1+T})$	$R_{\text{in}} = \frac{r_i}{1+T}$	$R_{\text{out}} = (1+T)\cdot r_o$	g-parameter