

# Lecture 29

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:

$$\begin{aligned}R_{\text{in}} &= \frac{V_i}{I_i} \\ &= \frac{(1+T) \cdot V_\varepsilon}{I_i} \\ &= (1+T) \cdot r_i\end{aligned}$$

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,

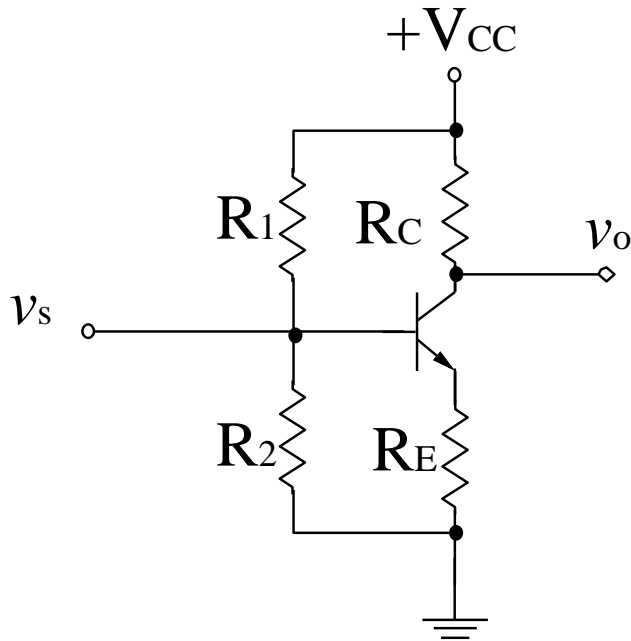
$$V_\varepsilon = V_f = -\beta \cdot I_o$$

from output port,

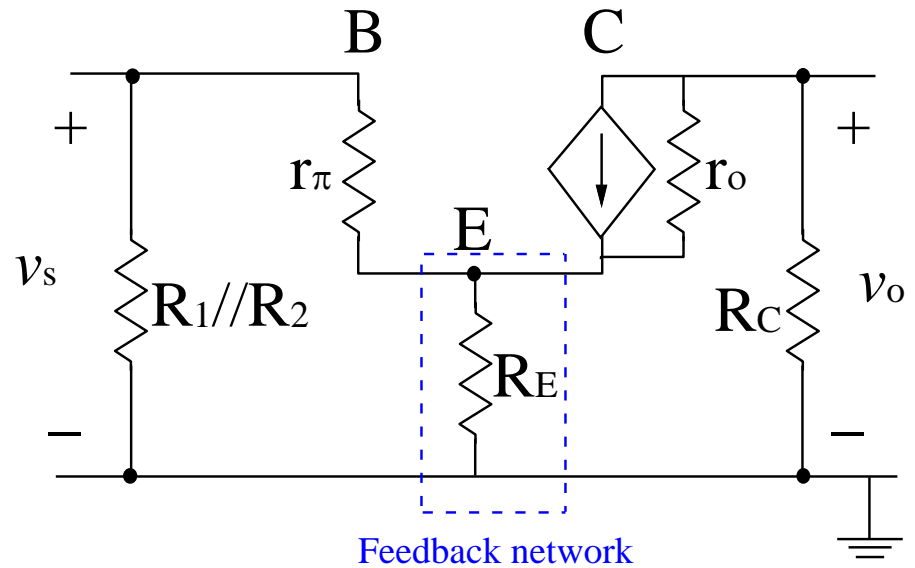
$$I_o = AV_\varepsilon + \frac{V_o}{r_o} = -T \cdot I_o + \frac{V_o}{r_o}$$

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

# 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,

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

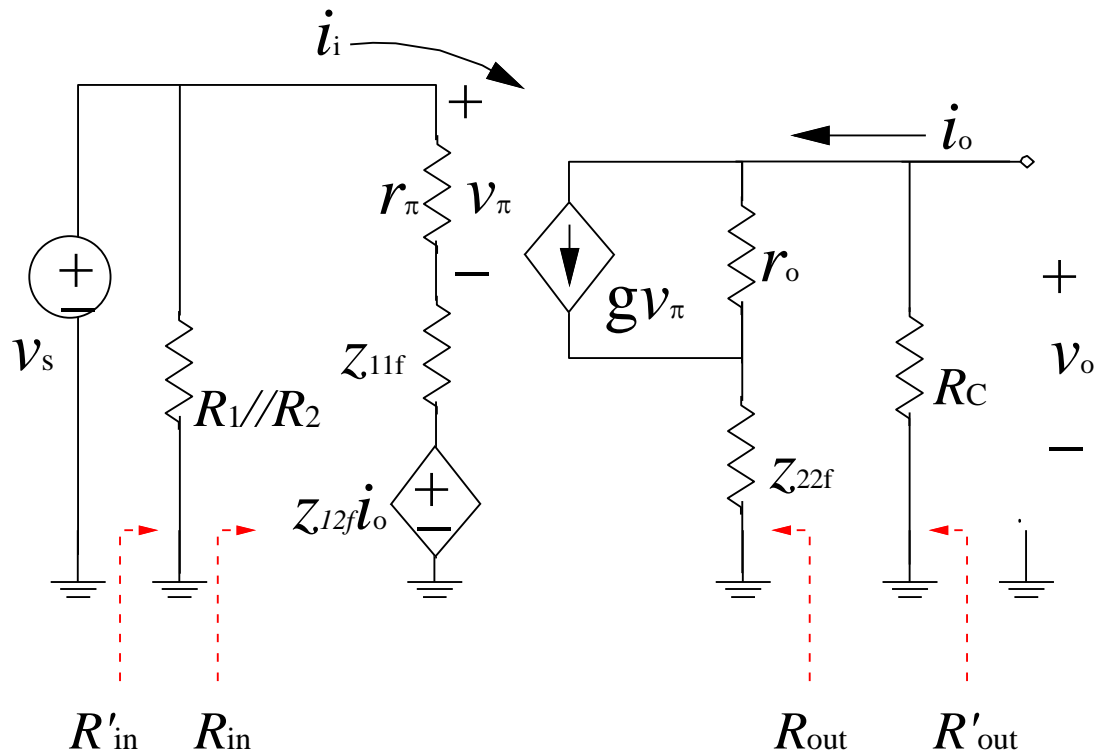
Input impedance is :

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

Output impedance is :

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

# Final $R_{in}$ and $R_{out}$



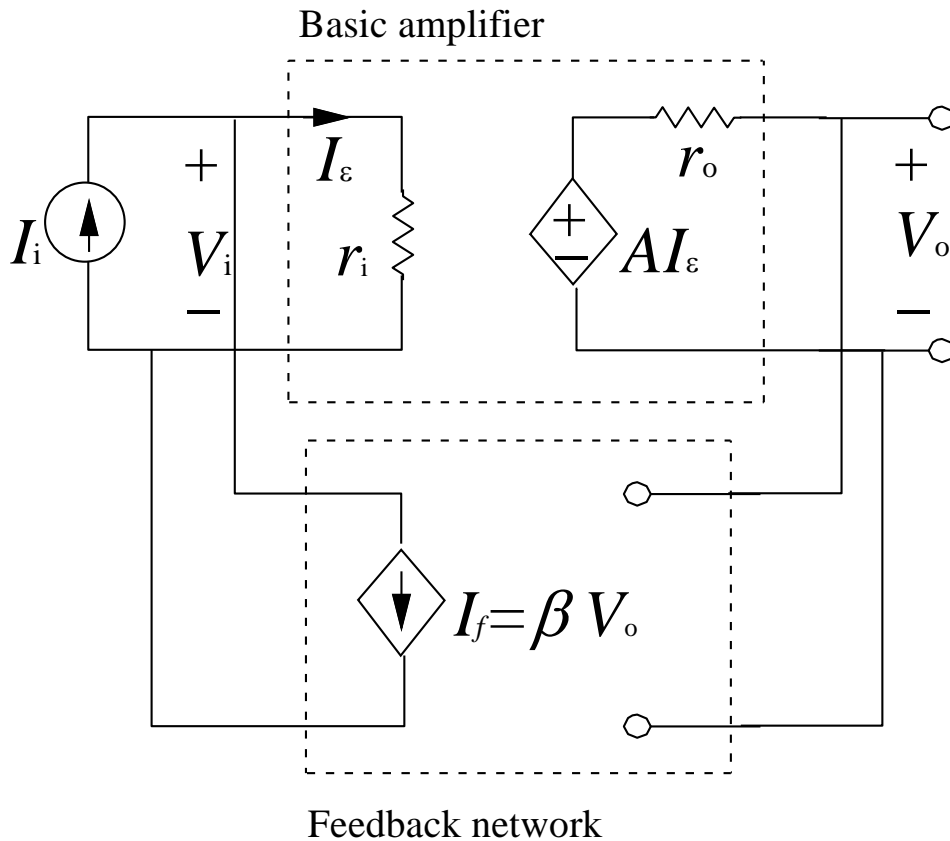
$$R'_{in} = R_{in} // R_1 // R_2$$

$$= [(r_\pi + R_E) + g r_\pi R_E] // R_1 // R_2$$

$$R'_{out} = R_{out} // R_C$$

$$= [(z_{22f})(1 + A_{OP}\beta)] // R_C$$

# Feedback Structure (Shunt-Shunt)



Gain Calculation :

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

$$I_f = \beta \cdot V_o$$

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

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

(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

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

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

# Input/Output Resistance (Shunt-Shunt)

Input Resistance:

$$\begin{aligned} R_{\text{in}} &= \frac{V_i}{I_i} \\ &= \frac{I_\varepsilon \cdot r_i}{I_\varepsilon (1+T)} \\ &= \frac{r_i}{(1+T)} \end{aligned}$$

Output Resistance

(Closed loop output resistance with zero input voltage)

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

from input port,

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

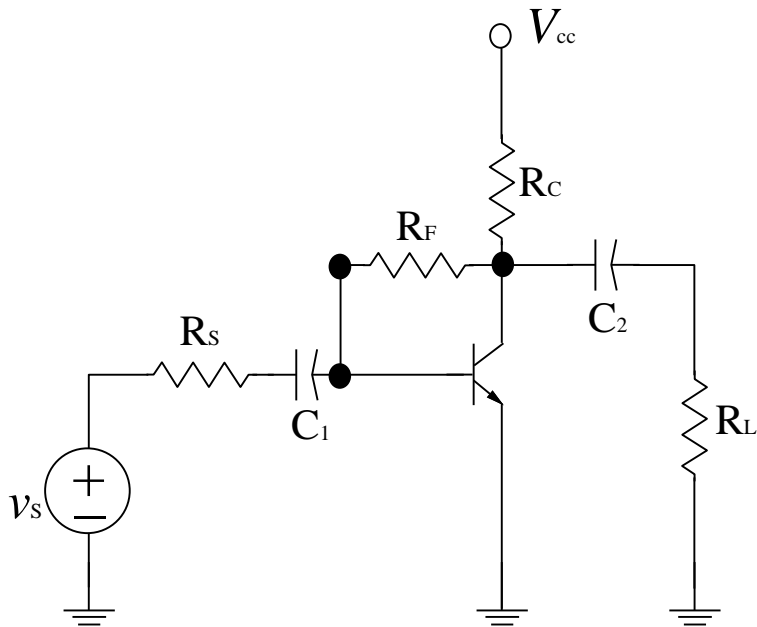
from output port,

$$I_o = \frac{V_o - A I_\varepsilon}{r_o} = \frac{V_o + T V_o}{r_o}$$

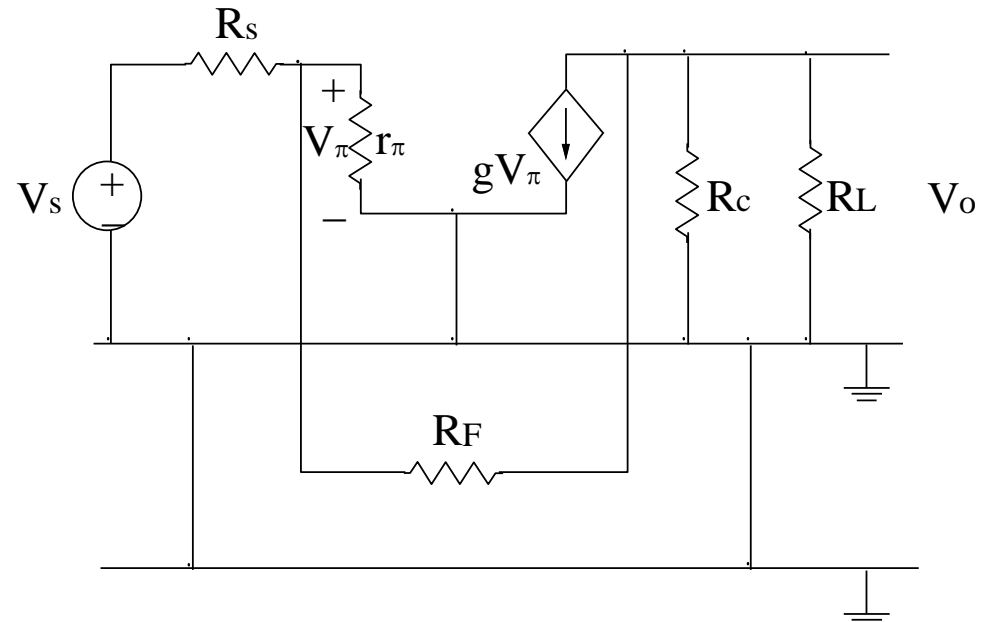
$$\Rightarrow R_{\text{out}} = \frac{V_o}{I_o} = \frac{r_o}{(1+T)}$$



# Shunt-Shunt Example



CE amplifier



ac small signal equivalent circuit

Shunt-Shunt connection found!  $\Rightarrow$  y-parameter

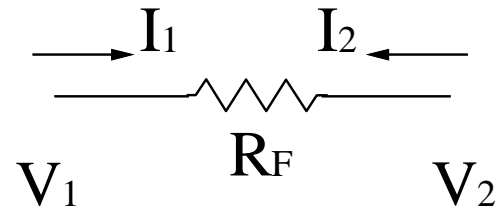
$$I_1 = y_{11}V_1 + y_{12}V_2$$

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

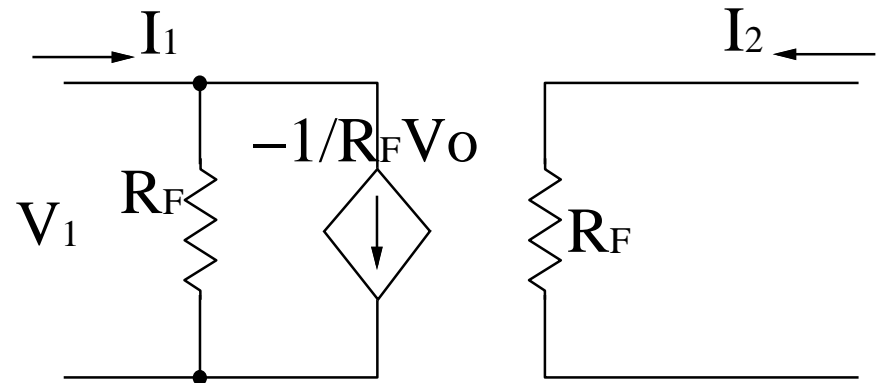
$$y_{11} = \left. \frac{I_1}{V_1} \right|_{V_2 = 0} = \frac{1}{R_F}$$

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

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



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,

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

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

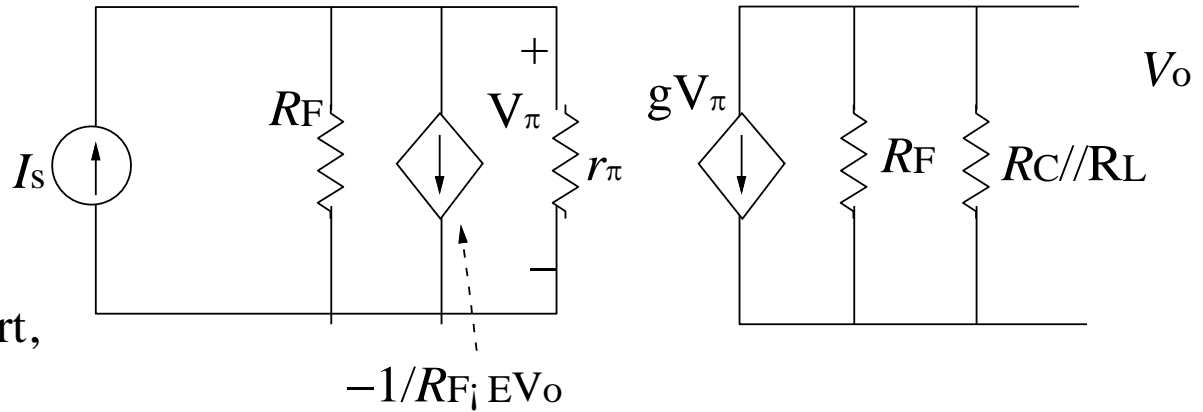
Open loop transimpedance gain :  $\frac{V_o}{I_S}$

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

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

the close loop transimpedance gain :

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



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

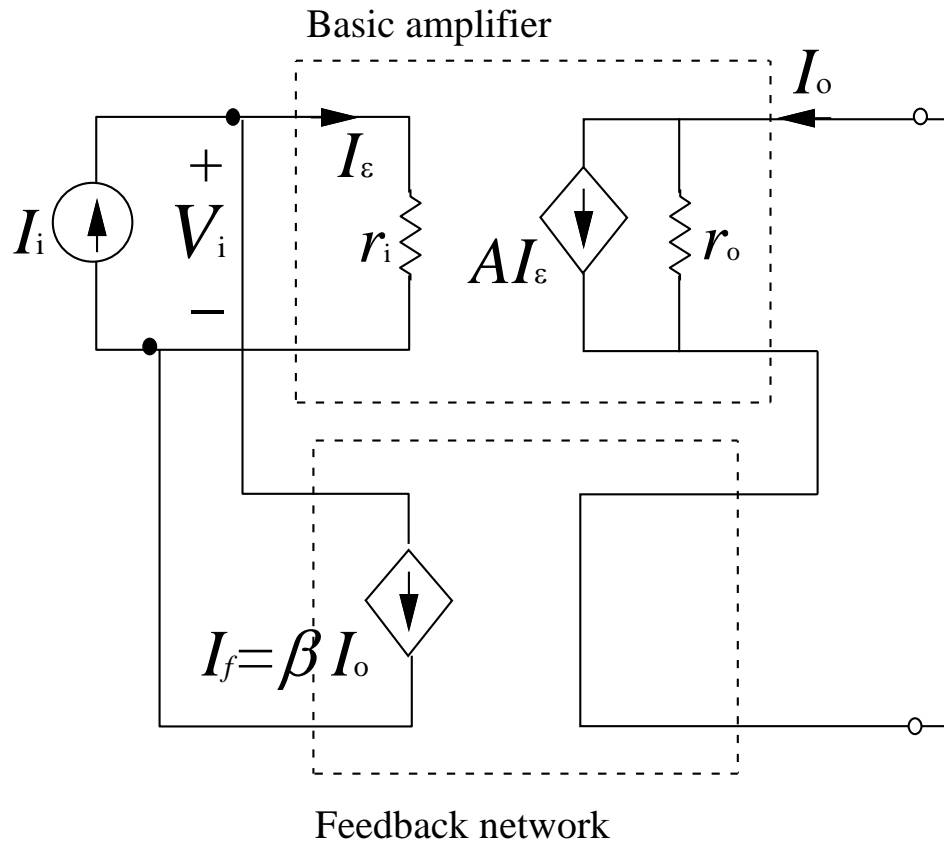
$$= \frac{(R_F // r_{\pi})}{(1 + A_{OP}\beta)}$$

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

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

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

# Feedback Structure (Shunt-Series)



Gain Calculation :

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

$$I_f = \beta \cdot I_o$$

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

$$A I_i = (1 + T) I_o$$

(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:

$$\begin{aligned} R_{\text{in}} &= \frac{V_i}{I_i} = \frac{I_\varepsilon r_i}{I_i} \\ &= \frac{I_i}{(1+T)} \cdot r_i \\ &= \frac{r_i}{(1+T)} \end{aligned}$$

Output Resistance

(Closed loop output resistance with zero input voltage)

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

from input port,

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

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	$\frac{V_o}{V_i} = \frac{1}{\beta} \left( \frac{T}{1+T} \right)$	$R_{in} = (1+T) \cdot r_i$	$R_{out} = \frac{r_o}{1+T}$	<i>h</i> -parameter
Series-Series	$\frac{I_o}{V_i} = \frac{1}{\beta} \left( \frac{T}{1+T} \right)$	$R_{in} = (1+T) \cdot r_i$	$R_{out} = (1+T) \cdot r_o$	<i>z</i> -parameter
Shunt-Shunt	$\frac{V_o}{I_i} = \frac{1}{\beta} \left( \frac{T}{1+T} \right)$	$R_{in} = \frac{r_i}{1+T}$	$R_{out} = \frac{r_o}{1+T}$	<i>y</i> -parameter
Shunt-Series	$\frac{I_o}{I_i} = \frac{1}{\beta} \left( \frac{T}{1+T} \right)$	$R_{in} = \frac{r_i}{1+T}$	$R_{out} = (1+T) \cdot r_o$	<i>g</i> -parameter