Huazhong University of Science & Technology

Electronic Circuit of Communications

School of Electronic Information and Commnications

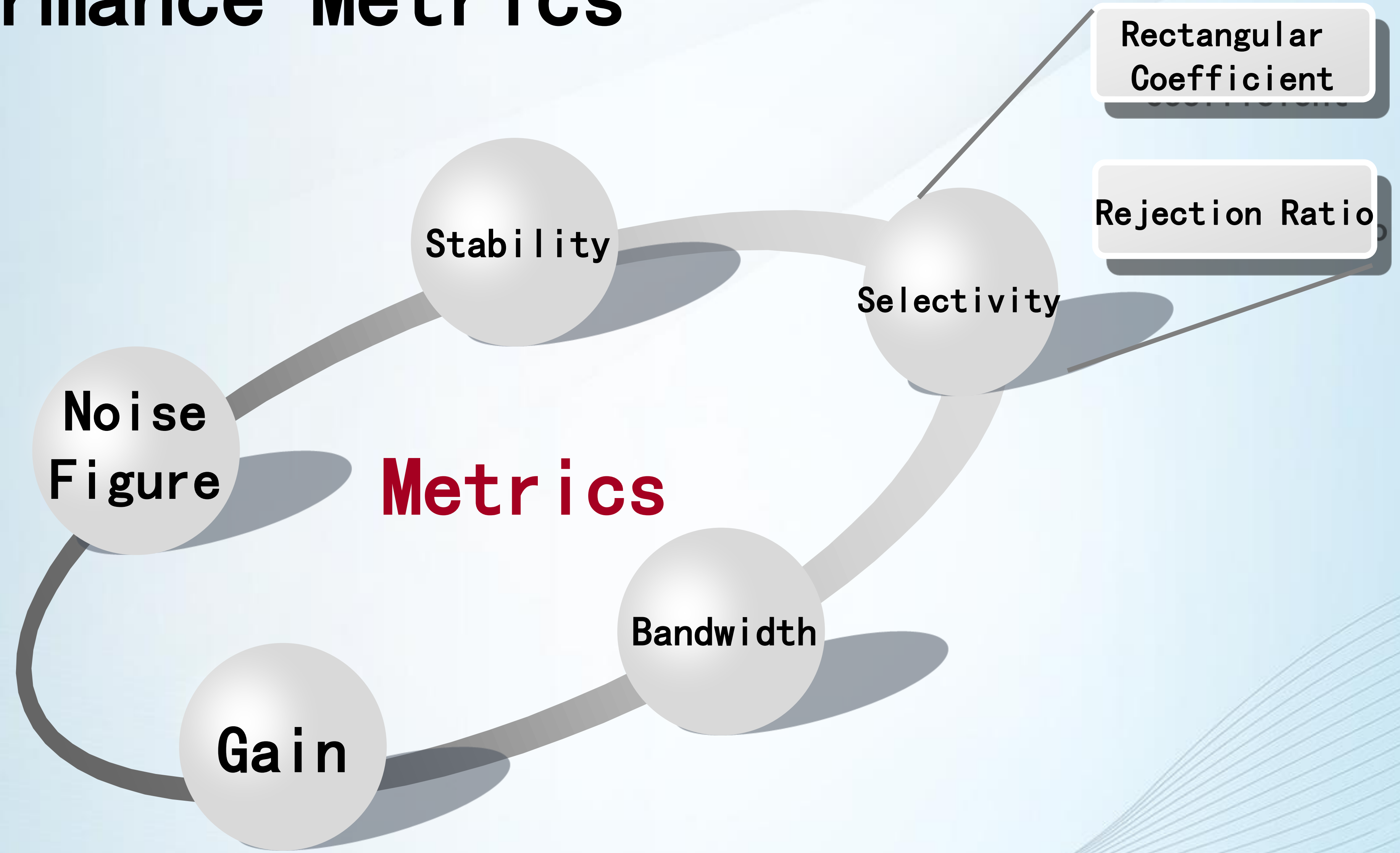
Jiaqing Huang

Small Signal Tuned Amplifier

Classification of Tuned Amplifier

- Devices：Transistor、FET、IC
- Stages：Single Stage, Mutiple Stage
- Bandwidth：NarrowBand, WideBand
- Load：Resonant, Non-Resonant

Performance Metrics



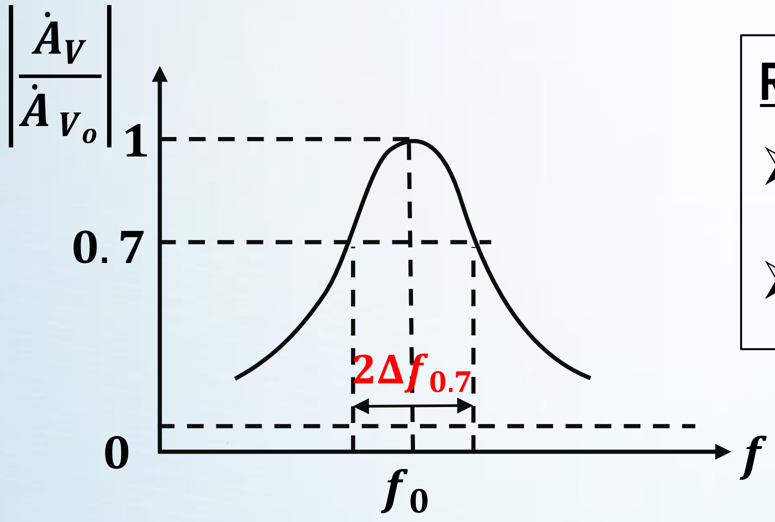
Performance Metrics

- **Gain**
  - Voltage Gain: $\dot{A}_V = \frac{\dot{V}_o}{\dot{V}_i}$
  - Power Gain: $A_P = \frac{P_o}{P_i}$

Performance Metrics

- **Bandwidth (3dB Bandwidth)**
  - $\dot{A}_V$ down to its 0.707

$$\left|\frac{\dot{A}_V}{\dot{A}_{V_O}}\right| = \frac{1}{\sqrt{2}} \quad \sim \quad 2\Delta f_{0.7} \text{ (Bandwidth)}$$

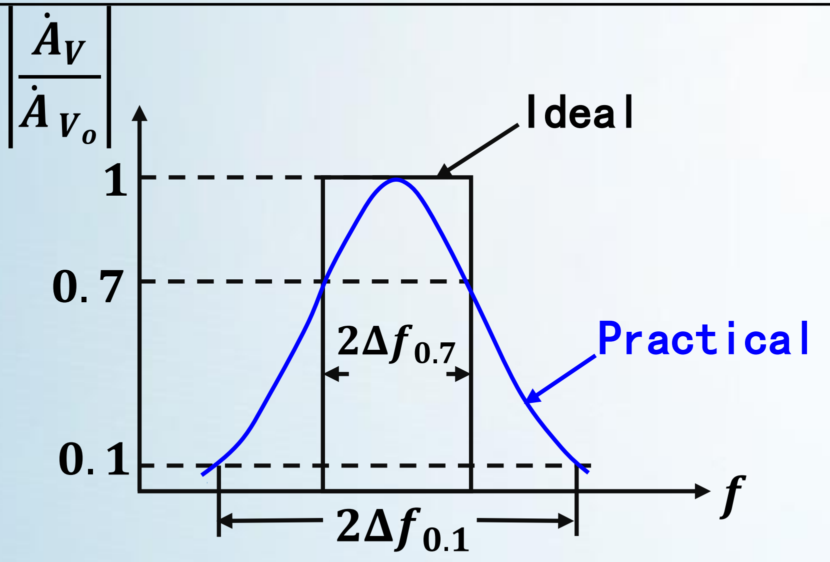
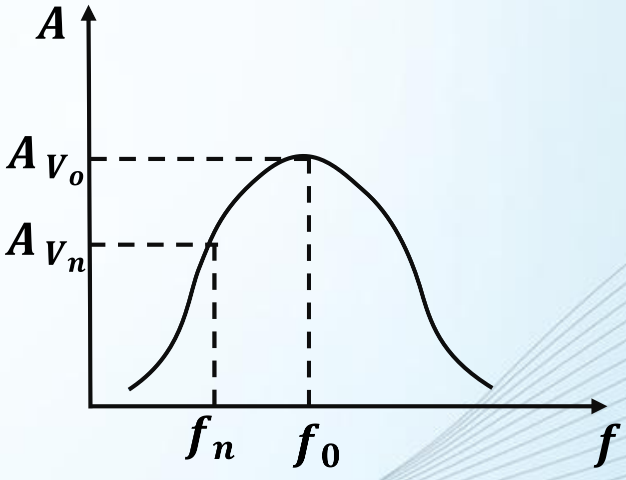


Review

- $|N(f)| = \left|\frac{\dot{I}}{\dot{I}_0}\right| = \frac{1}{\sqrt{2}} \sim 2\Delta f_{0.7}$ (Series Curve)
- $|N(f)| = \left|\frac{\dot{V}}{\dot{V}_0}\right| = \frac{1}{\sqrt{2}} \sim 2\Delta f_{0.7}$ (Parallel Curve)

Performance Metrics

- **Selectivity:**

Rectangular Coefficient $K_{r0.1} = \frac{2\Delta f_{0.1}}{2\Delta f_{0.7}}$	Rejection Ratio $d_n = \frac{A_{V_o}}{A_{V_n}}$
How close to ideal	Rejection to f_n
	

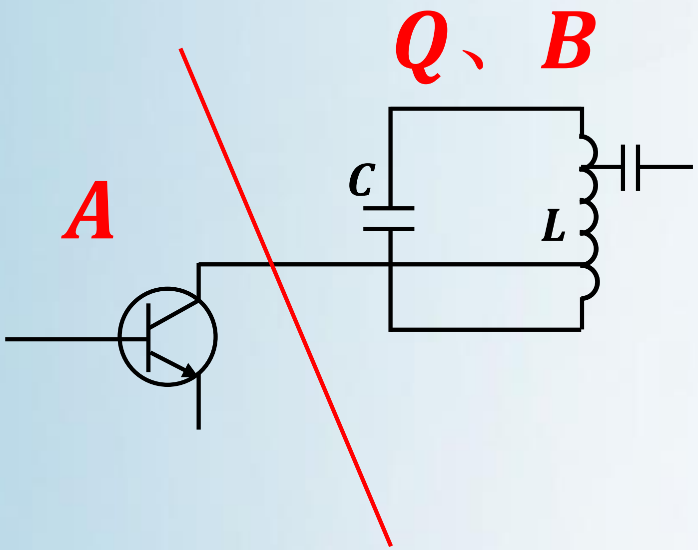
Performance Metrics

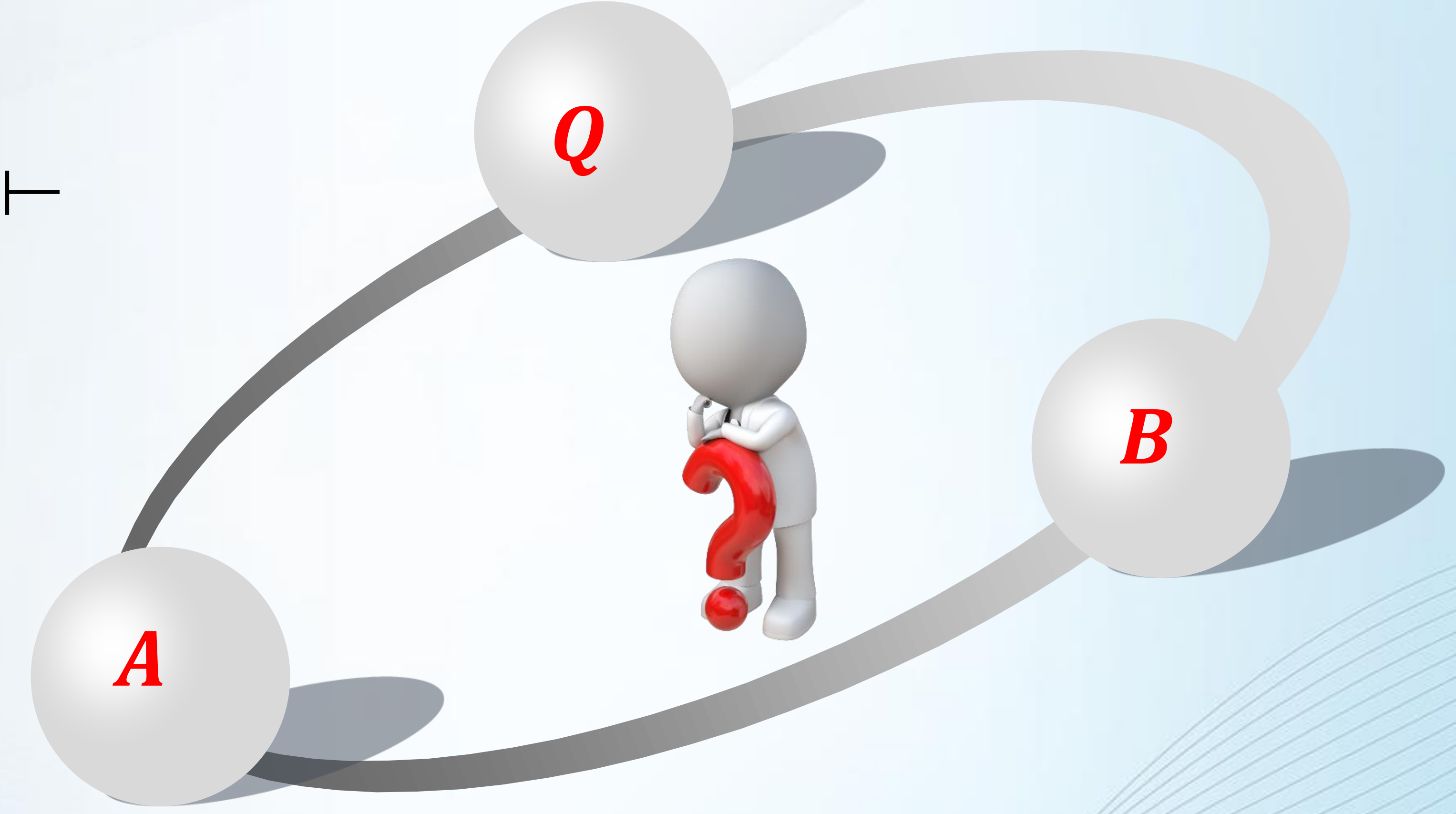
- Stability
  - Stability Coefficent

- Noise Figure N_F
  - N_F the closer to 1, the better

$$N_F = \frac{S_i/N_i}{S_o/N_o}$$

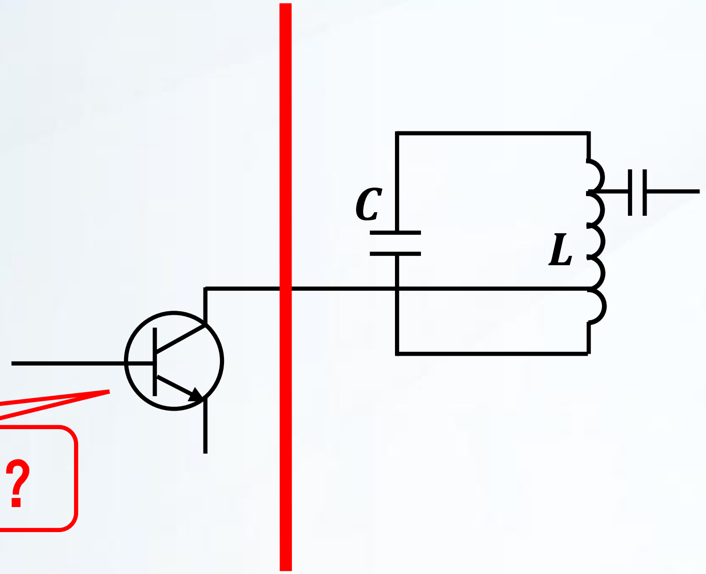
Key Relationship





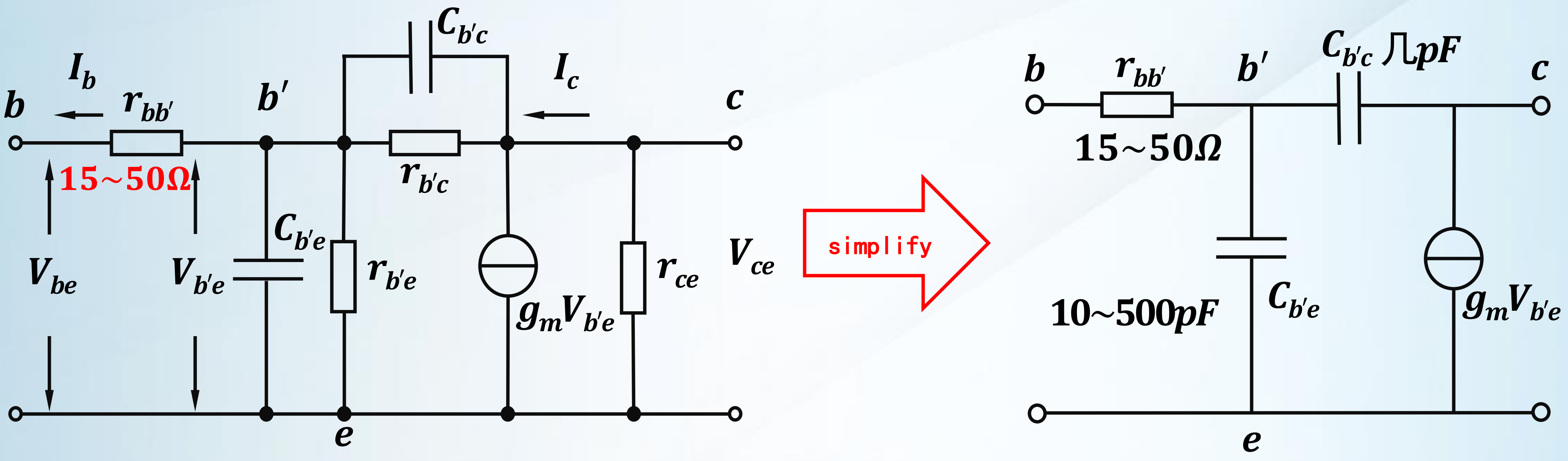
Equivalent Circuit

Small Signal Tuned Amplifier



Equivalent Circuit?

Hybrid π Equivalent Circuit



$r_{bb'}$ Base Resistance

$C_{b'e}$ PN Capacitance

$C_{b'c}$ PN Capacitance

Stability

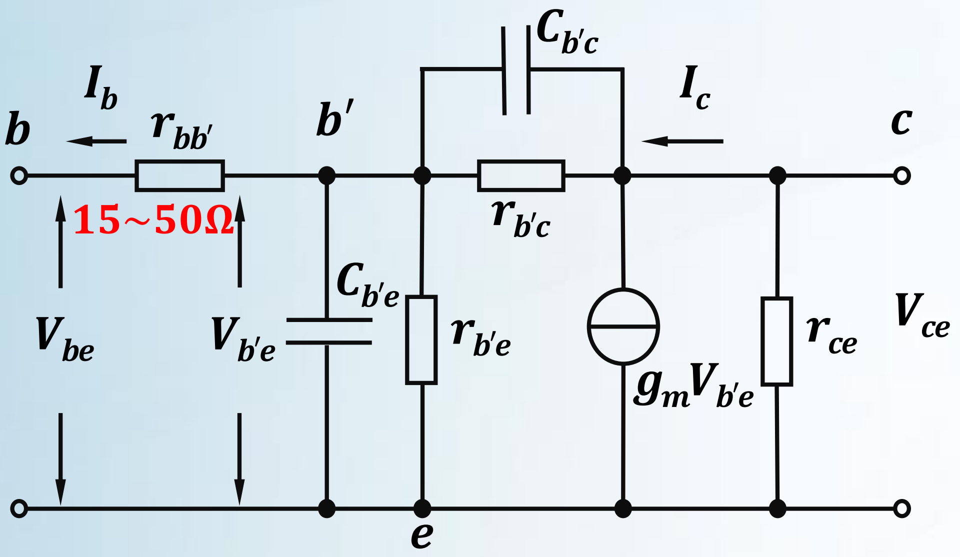
$r_{b'e}$ $\Rightarrow r_{b'e} > C_{b'e}$, Open

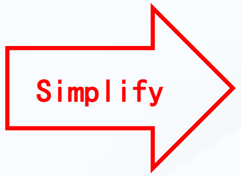
$r_{b'c}$ $\Rightarrow r_{b'c} > C_{b'c}$, Open

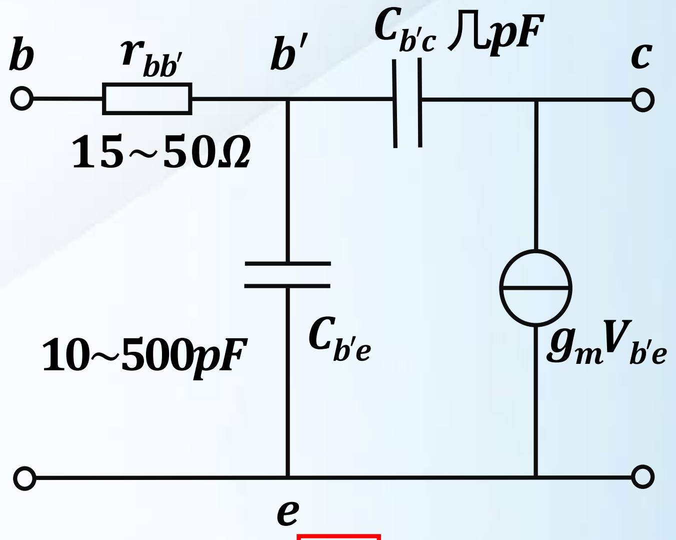
r_{ce} $\Rightarrow r_{ce} >$ Load, Open

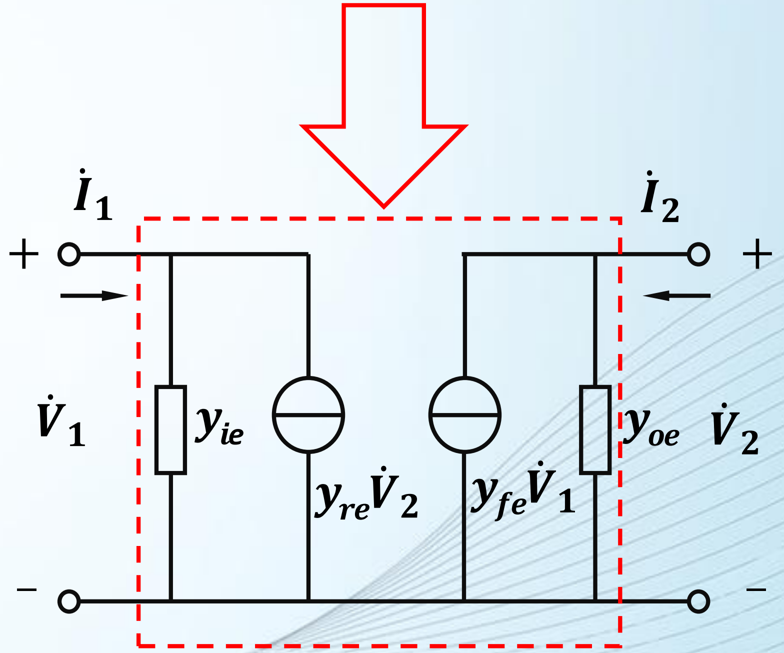
$g_m V_{b'e}$ current source, amplify ability (g_m transconductance)

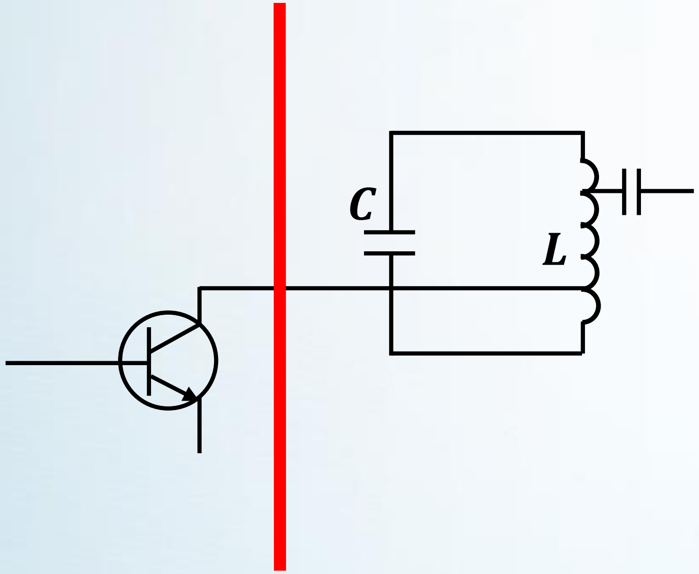
Hybrid π Equivalent Circuit











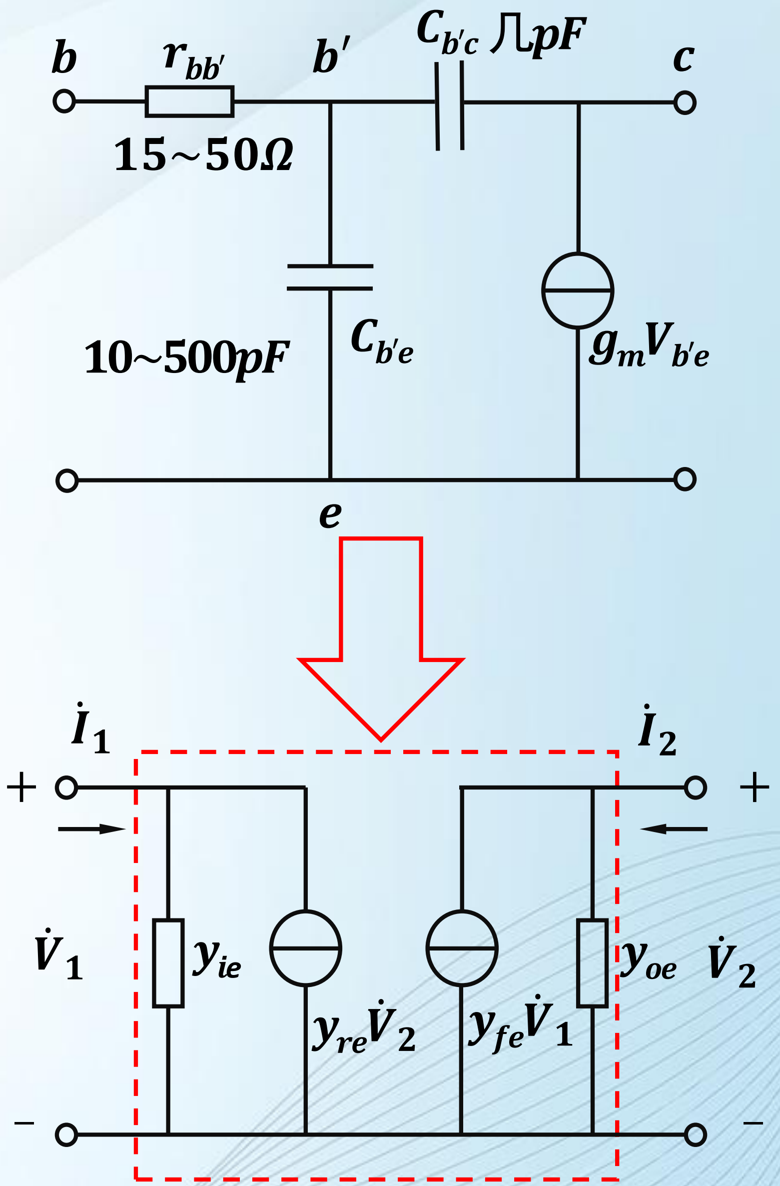
Y Parameter Equivalent Circuit

Input Admittance: $y_{ie}=\left.\frac{\dot{I}_1}{\dot{V}_1}\right|_{\dot{V}_2=0}=\frac{Y_{b'e}}{1+r_{bb'}Y_{b'e}}$

Forward Tranfer Admittance: $y_{fe}=\left.\frac{\dot{I}_2}{\dot{V}_1}\right|_{\dot{V}_2=0}=\frac{g_m}{1+r_{bb'}Y_{b'e}}$

Reverse Tranfer Admittance : $y_{re}=\left.\frac{\dot{I}_1}{\dot{V}_2}\right|_{\dot{V}_1=0}=-\frac{j\omega C_{b'c}}{1+r_{bb'}Y'_{b'e}}$

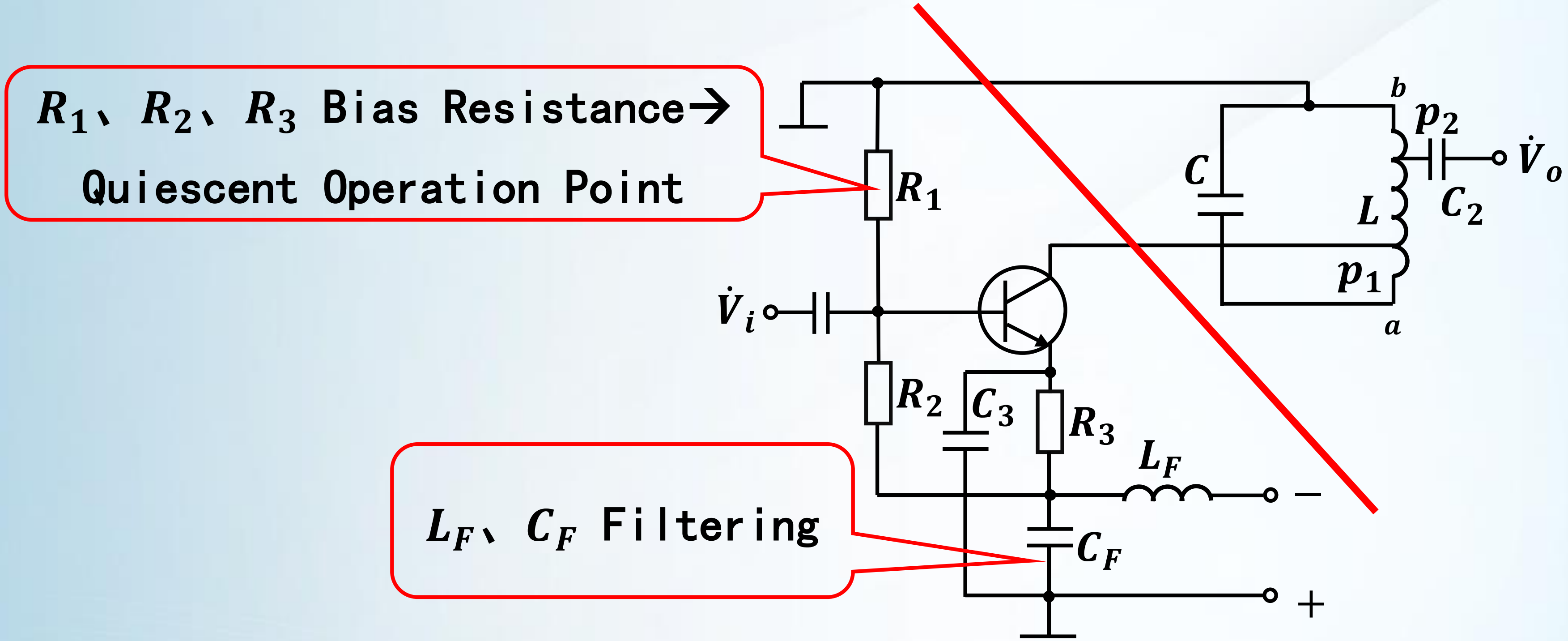
Output Admittance: $y_{oe}=\left.\frac{\dot{I}_2}{\dot{V}_2}\right|_{\dot{V}_1=0}=j\omega C_{b'c}\left(1+\frac{g_m r_{bb'}}{1+r_{bb'}Y'_{b'e}}\right)$



Gain

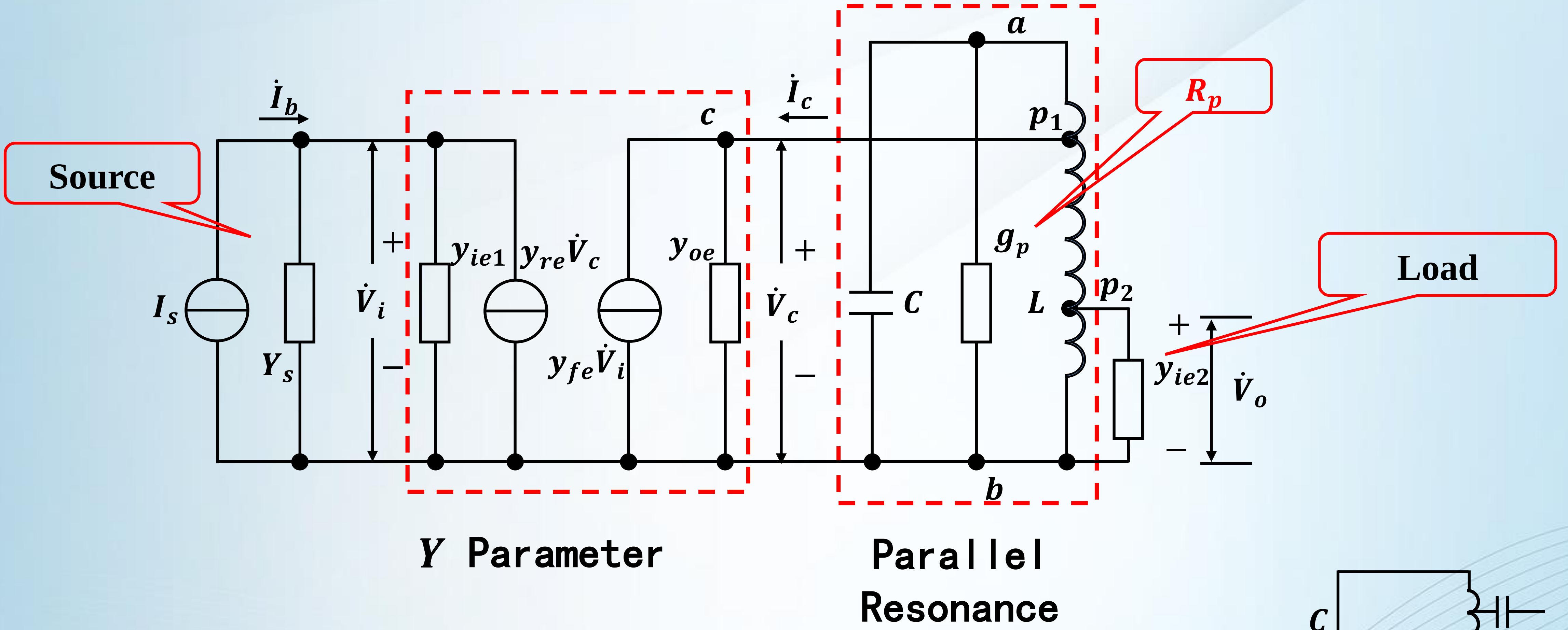
Small Signal Tuned Amplifier

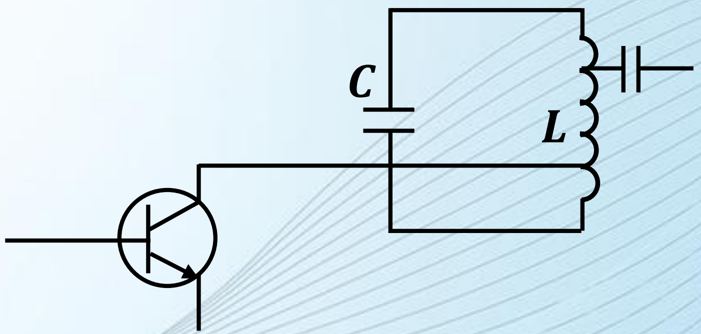
- Clue: ⇒ Gain、B、Selectivity



Y Parameter + Parallel Resonance (With Tap)

Equivalent Circuit





★Do not miss R_p

Gain

$$\begin{cases} \dot{I}_b = y_{ie}\dot{V}_i + y_{re}\dot{V}_c & (1) \\ \dot{I}_c = y_{fe}\dot{V}_i + y_{oe}\dot{V}_c & (2) \\ \dot{I}_c = -\dot{V}_c Y'_L & (3) \end{cases}$$

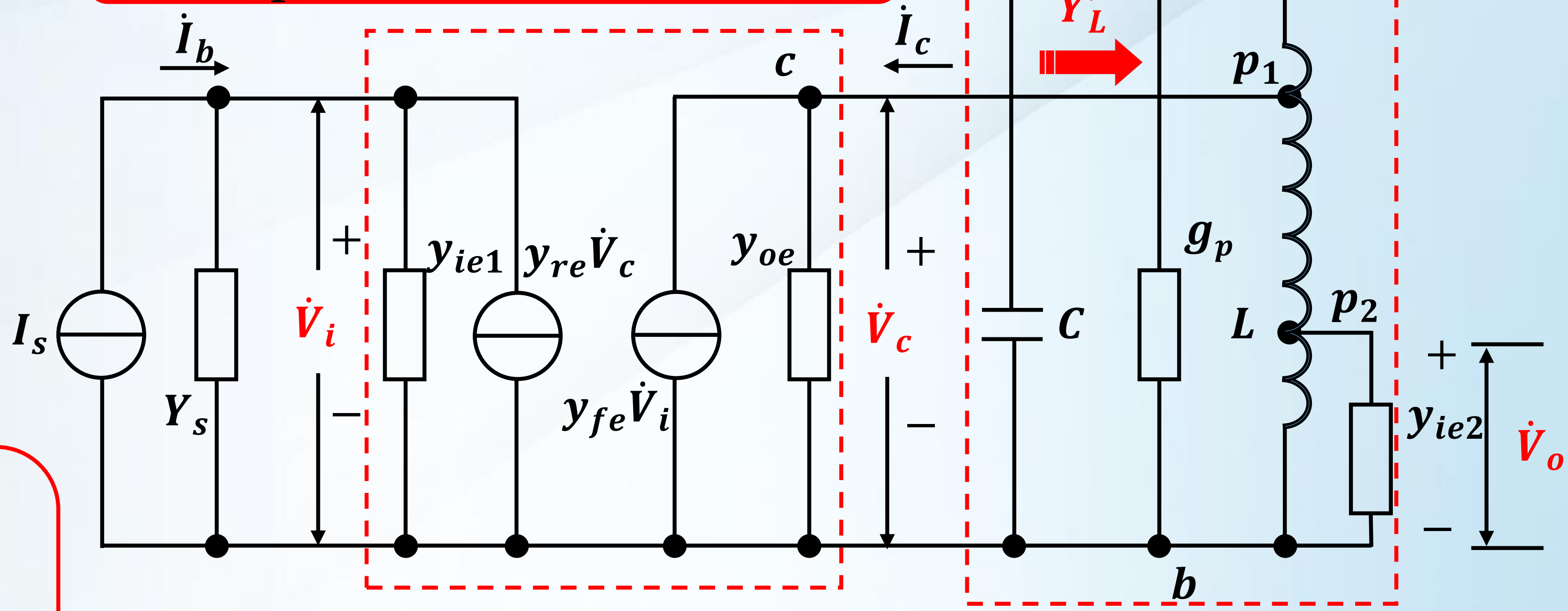
Y'_L From right of collecor c

$$Y'_L = \frac{1}{p_1^2}\left(g_p + j\omega C + \frac{1}{j\omega L} + p_2^2 y_{ie2}\right)$$

$\because (3) = (2)$

$$\Rightarrow \dot{V}_c = -\frac{y_{fe}}{y_{oe}+Y'_L}\dot{V}_i \quad (4)$$

$$Y'_L = \frac{1}{p_1^2}\left(g_p + j\omega C + \frac{1}{j\omega L} + p_2^2 y_{ie2}\right)$$

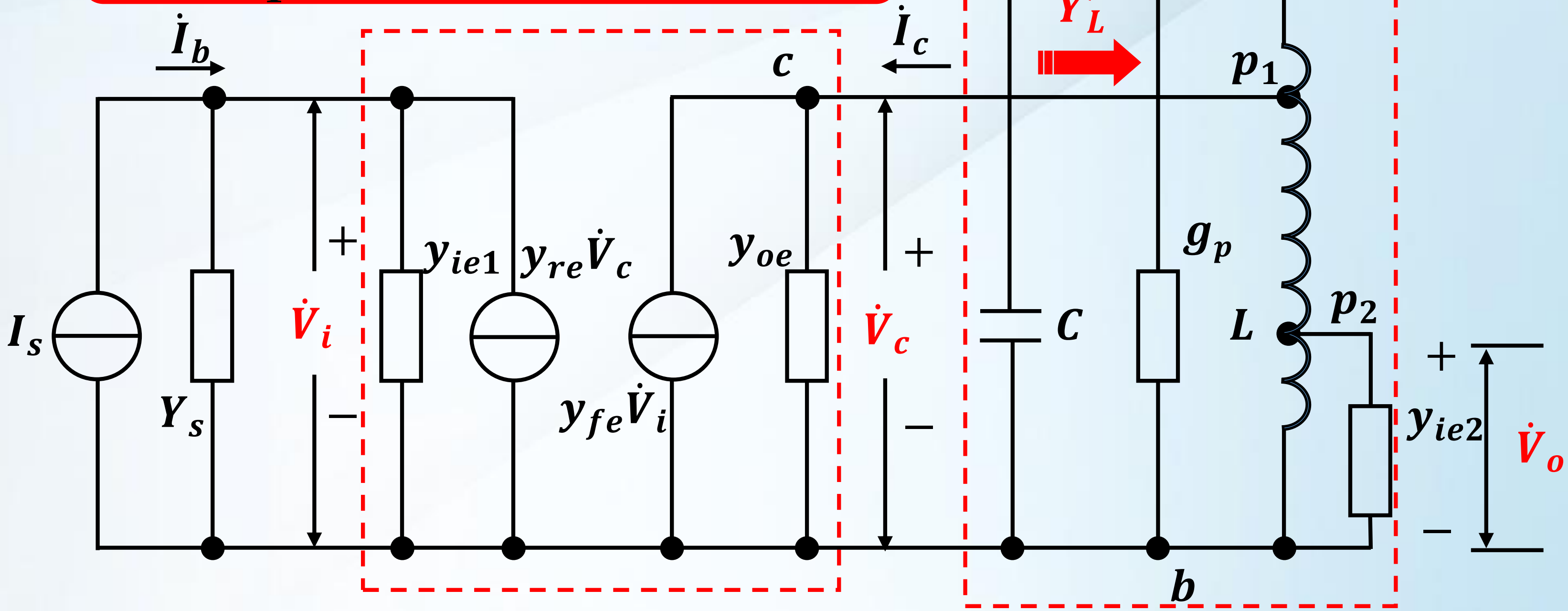


$\dot{V}_i$ $\dot{V}_c$ $\dot{V}_o$

$$\dot{V}_c = -\frac{y_{fe}}{y_{oe}+Y'_L}\dot{V}_i$$

$$\dot{A}_V = \frac{\dot{V}_o}{\dot{V}_i}$$

Gain



$$Y_L' = \frac{1}{p_1^2}\left(g_p + j\omega C + \frac{1}{j\omega L} + p_2^2 y_{ie2}\right)$$

Tap p_1 p_2:

$$\left.\begin{aligned}\dot V_o &= p_2 \dot V_{ab}\\ \dot V_c &= p_1 \dot V_{ab}\end{aligned}\right\} \Rightarrow \dot V_o = \frac{p_2}{p_1}\dot V_c$$

$\dot V_i$ $\xrightarrow{\quad}$ $\dot V_c$ $\xrightarrow{\quad}$ $\dot V_o$

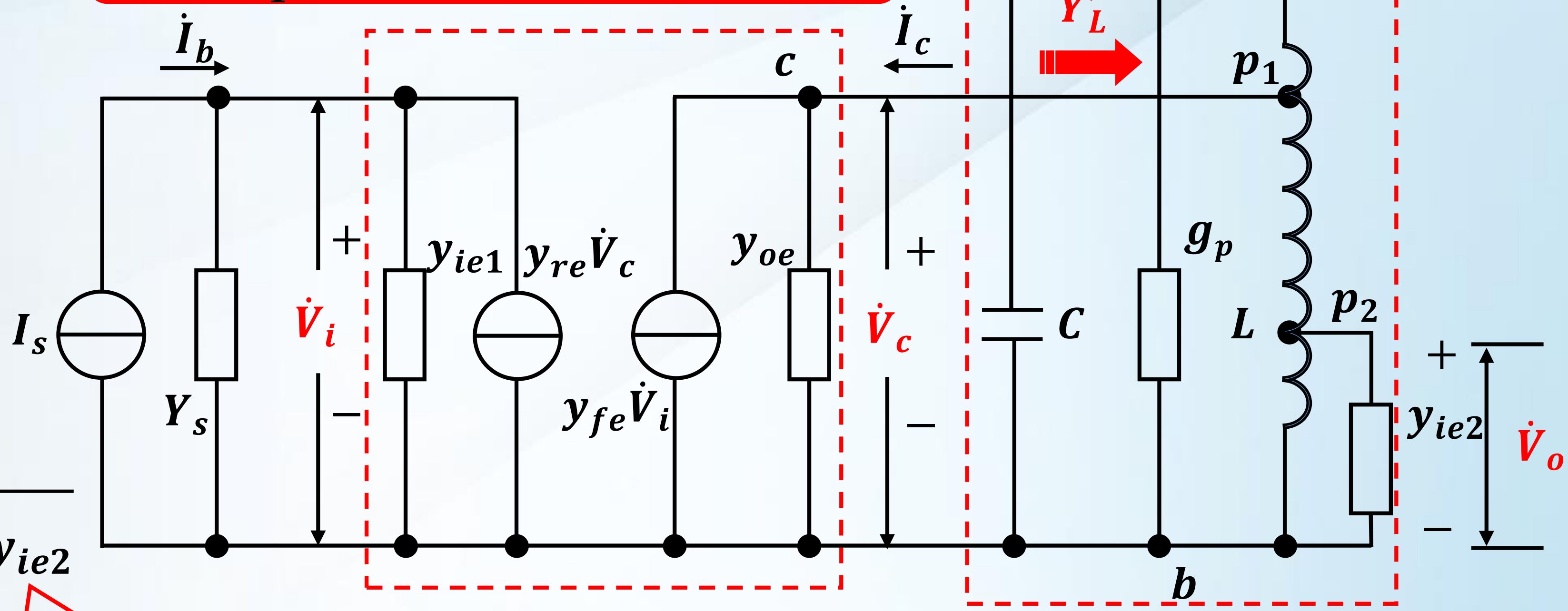
$$\dot V_c = -\frac{y_{fe}}{y_{oe} + Y_L'}\dot V_i$$

$$\dot V_o = \frac{p_2}{p_1}\dot V_c$$

$$\dot A_V = \frac{\dot V_o}{\dot V_i}$$

Gain

$$Y_L' = \frac{1}{p_1^2}\left(g_p + j\omega C + \frac{1}{j\omega L} + p_2^2 y_{ie2}\right)$$



$$\dot{A}_V = \frac{\dot{V}_o}{\dot{V}_i}$$

$$= \frac{p_2}{p_1}\frac{\dot{V}_c}{\dot{V}_i} = -\frac{p_2 y_{fe}}{p_1\left(y_{oe} + Y_L'\right)}$$

$$= -\frac{p_1 p_2 y_{fe}}{p_1^2 y_{oe} + \boxed{g_p + j\omega C + \frac{1}{j\omega L}} + p_2^2 y_{ie2}}$$

$y_{oe} = g_{oe} + j\omega C_{oe}$

$y_{ie2} = g_{ie2} + j\omega C_{ie2}$

$$= \frac{-p_1 p_2 y_{fe}}{\underbrace{\left(p_1^2 g_{oe} + g_p + p_2^2 g_{ie2}\right)}_{g_\Sigma} + j\omega \underbrace{\left(p_1^2 C_{oe} + C + p_2^2 C_{ie2}\right)}_{C_\Sigma} + \frac{1}{j\omega L}}$$

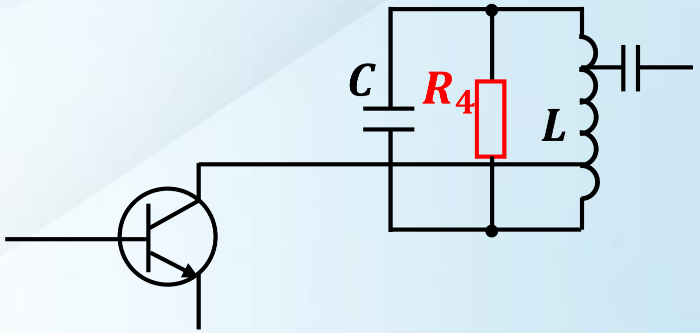
$\dot{V}_i \quad \dot{V}_c \quad \dot{V}_o$

$$\dot{V}_c = -\frac{y_{fe}}{y_{oe} + Y_L'}\dot{V}_i$$

$$\dot{V}_o = \frac{p_2}{p_1}\dot{V}_c$$

$$\Rightarrow \dot{A}_V = \frac{-p_1 p_2 y_{fe}}{g_\Sigma + j\omega C_\Sigma + \frac{1}{j\omega L}}$$

Gain



$$\dot{A}_V = \frac{\dot{V}_o}{\dot{V}_i}$$

$$\dot{A}_V = \frac{-p_1 p_2 y_{fe}}{g_\Sigma + \boxed{j\omega C_\Sigma + \frac{1}{j\omega L}}}$$

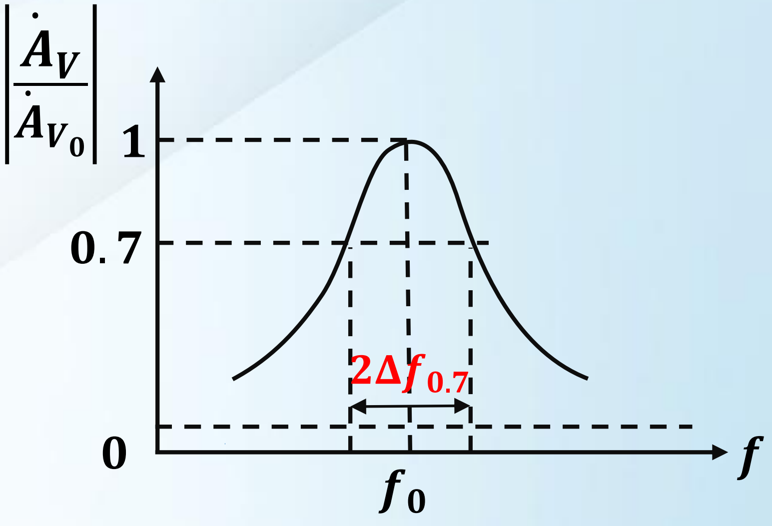
$$\left(p_1^2 g_{oe} + g_p + p_2^2 g_{ie2}\right)$$

$$\dot{A}_{V_0} = \frac{-p_1 p_2 y_{fe}}{g_\Sigma}$$

Resonant, $j\omega C_\Sigma + \frac{1}{j\omega L} = 0$

Bandwidth & Selectivity

Bandwidth



- Bandwidth: $2\Delta f_{0.7}$

$$\left|\frac{\dot{A}_V}{\dot{A}_{V_0}}\right| = \frac{1}{\sqrt{2}} \quad \sim \quad 2\Delta f_{0.7}$$

$$\left.\begin{aligned} \dot{A}_V &= \frac{-p_1 p_2 y_{fe}}{g_\Sigma + j\omega C_\Sigma + \frac{1}{j\omega L}} = \frac{-p_1 p_2 y_{fe}}{g_\Sigma + j\left(\omega C_\Sigma - \frac{1}{\omega L}\right)} = \frac{-p_1 p_2 y_{fe}}{g_\Sigma (1 + j\xi)} \\ \dot{A}_{V_0} &= \frac{-p_1 p_2 y_{fe}}{g_\Sigma} \end{aligned}\right\} \Rightarrow \frac{\dot{A}_V}{\dot{A}_{V_0}} = \frac{1}{1 + j\xi}$$

$$\xi = \frac{\omega C - \frac{1}{\omega L}}{G} \approx Q \cdot \frac{2\Delta f}{f_p}$$

Bandwidth *vs.* Quality Factor

$$\left.\begin{aligned} &\frac{\dot{A}_V}{\dot{A}_{V_0}} = \frac{1}{1+j\xi} \\ &\left|\frac{\dot{A}_V}{\dot{A}_{V_0}}\right| = \frac{1}{\sqrt{1+\xi^2}} = \frac{1}{\sqrt{2}} \end{aligned}\right\} \Rightarrow \text{当} 2\Delta f = 2\Delta f_{0.7}$$

$$\left.\begin{aligned} &\xi = 1 \\ &\xi = Q_L \cdot \frac{2\Delta f}{f_p} \end{aligned}\right\} \Rightarrow 1 = Q_L \cdot \frac{2\Delta f_{0.7}}{f_p}$$

$$2\Delta f = 2\Delta f_{0.7}$$

Note: $Q_L \cdot B = f_p$

Bandwidth *vs.* Gain

$$Q_L = \frac{\frac{1}{\omega_0 L}}{g_\Sigma} = \frac{\omega_0 C_\Sigma}{g_\Sigma} \quad \Rightarrow g_\Sigma = \frac{\omega_0 C_\Sigma}{Q_L} = \frac{2\pi f_0 C_\Sigma}{\frac{f_0}{2\Delta f_{0.7}}} = 2\pi C_\Sigma \cdot 2\Delta f_{0.7}$$

$$Q_L \cdot 2\Delta f_{0.7} = f_0$$

$$\dot{A}_{V_0} = \frac{-p_1 p_2 y_{fe}}{g_\Sigma} = -\frac{p_1 p_2 y_{fe}}{2\pi C_\Sigma \cdot 2\Delta f_{0.7}}$$

$$\Rightarrow \left| A_{V_0} \cdot 2\Delta f_{0.7} \right| = \frac{\left| p_1 p_2 y_{fe} \right|}{2\pi C_\Sigma}$$

Note: Constant

Selectivity（Rectangle Coefficient）

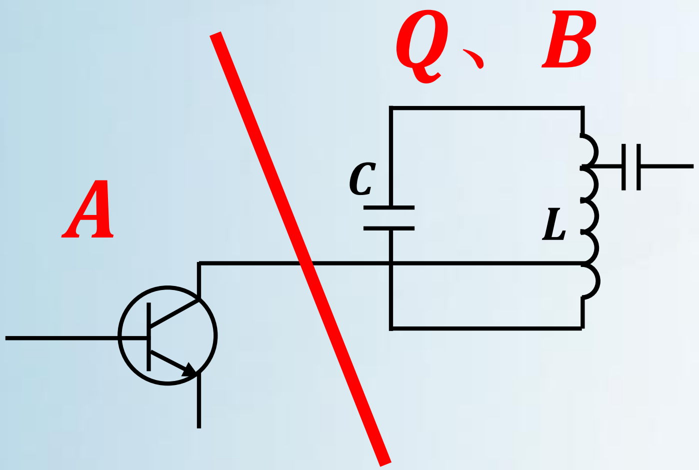
$$\left|\frac{\dot{A}_V}{\dot{A}_{V_0}}\right| = \frac{1}{\sqrt{1+\left(Q_L\frac{2\Delta f_{0.1}}{f_p}\right)^2}} = 0.1$$

$$\Rightarrow 2\Delta f_{0.1} = \sqrt{10^2-1}\cdot\frac{f_p}{Q_L} = \sqrt{10^2-1}\cdot 2\Delta f_{0.7}$$

$$K_{r0.1} = \frac{2\Delta f_{0.1}}{2\Delta f_{0.7}} = \sqrt{10^2-1} = 9.9499$$

Note：Far away from ideal 1

Summary



Selectivity